MiS20
the robotic soccer simulator
- Bachelor thesis -

Names:	Hans Dollen
	Wim Fikkert
Date:	June, 13th 2003
Version:	1.0

Title:	MiS20, the robotic soccer simulator
Version:	1.0
Authors:	Hans Dollen Wim Fikkert
Company name:	University Twente
Department:	TKI
Company tutor:	Dr. M. Poel
Saxion tutors:	Ir. J. Meuleman R.F. Lever
Date:	June, 13th 2003
Location:	Enschede, The Netherlands

Summary

Robot soccer is an international research effort the goal of which is to explore and apply new and promising techniques in the field of robotics. The University of Twente is trying to set up its own AI controlled team (Mi20, or Mission Impossible Twente) in the FIRA MiroSot middle league. This team needs to be trained and tested in a simulator program. The simulator currently in use does not meet all requirements set by the Mi20 team. The creation of a new simulator (MiS20, or Mission Impossible Simulator) is required. Our project goal therefore states:

> *Create a new realistic simulator for a five against five robot soccer match played according to the FIRA MiroSot middle league game rules. The robots and the ball must simulate their real counterparts in an approximately correct way.*

This project goal raises a research question which needs to be answered in this project:

> *When does the level of simulation of the robots and the ball reach the required level of an approximately correct simulation; which physical aspects need to be taken into account?*

The MiS20 was designed using three software design methods; NIAM, OVID and UML. These methods complement each other in a way that leads to a design which contains all aspects of the simulator program. The MiS20 was implemented in Java, using CVS and a source code template and was fully documented using Sun's javadoc.

Various available robot soccer research documents were used to create a dynamic and kinematic representation of the robots and the ball which simulates their real counterparts in an approximately correct way.

Samenvatting

Robot voetbal is een internationaal onderzoeksproject waarvan het doel is om nieuwe en veel belovende technieken op het gebied van robotica toe te passen en te onderzoeken. De Universiteit Twente is bezig om een door Kunstmatige Intelligentie (KI) aangestuurd team (Mi20, ookwel Mission Impossible) op te zetten. Dit team moet worden getraind en getest m.b.v. een simulator. De simulator welke momenteel in gebruik is voldoet niet aan alle eisen welke het Mi20 team stelt. Hierdoor is het noodzakelijk om een nieuwe simulator te ontwikkelen, genaamd MiS20 (hetgeen staat voor Mission Impossible Simulator). Deze ontwikkeling staat beschreven in dit document. Onze project doelstelling luidt dan ook:

> *Maak een nieuwe simulator waarin een vijf tegen vijf robot voetbal wedstrijd, conform de FIRA MiroSot middle league spelregels, gespeeld kan worden. De robots en de bal moeten hun echte equivalente tegenhanger zo goed mogelijk simuleren.*

Hierbij doet zich een onderzoeksvraag aan welke in dit project beantwoord moet worden:

> *Welke mate van simulatie precisie is voldoende om aan het geëiste niveau van simulatie te kunnen voldoen; welke natuurkundige aspecten moeten hierbij betrokken worden?*

De simulator is ontworpen door gebruik te maken van drie software ontwerp methoden; NIAM, OVID en UML. Deze methoden vullen elkaar in dusdanige mate aan, dat het resultaat een ontwerp is waarbij alle aspecten van de simulator aan bod komen. Hierna is de simulator geïmplementeerd in Java, m.b.v. CVS en een source code template. Tijdens dit proces is de source code uitgebreid gedocumenteerd middels Sun's javadoc.

Tenslotte is er een dynamisch en kinematisch model gemaakt van de robots en de bal door gebruik te maken van diverse beschikbare robot voetbal onderzoeksdocumenten.

Preface

This document marks the final phase of our education at the Saxion Hogeschool Enschede. We have tried to describe in detail our activities these last 20 weeks regarding our bachelor thesis project, short summaries regarding studied literature and theories and the choices we have had to make.

When we started this project we actually had no knowledge of robotic soccer other than a short documentary on the television. We started off by doing a lot of reading, in the mean time getting more and more on the subject. Eventually we have had to put a lot of hard work on documenting our entire venture because that was the thing often overlooked whilst programming and researching.

We would like to thank Jan Meuleman and Mannes Poel for supporting us on various fronts during our project, our families for having to put with our “interesting” robot soccer stories and the remaining UT staff whom we “bothered” the last few months, Hendri Hondorp in particular. We would also like to thank our review team; André van der Zijden, Michiel Korthuis and Lynn Packwood. And last but not least, we would like to thank the Mi20 team, Werner, Niek and Remco for us having a great time with them on the Mi20 project.

This document is accompanied by a CD-Rom disc containing all products we created during our project. The file tree below indicates which items can be found at what location.

- readme
- docs
  - Start-document
  - FINAL-document
  - Implementation-document
  - DESIGN-document
  - Test-document
- src
  - javadoc
  - simulator

Table of Contents

Illustration Index

1. About

1.1. Context

Robot soccer is an international research effort the goal of which is to explore and apply new and promising techniques in the field of robotics. Example technologies are multi-agent systems, sensor fusion, machine learning and planning. Since 1997 a robot soccer competition has taken place each year in which a lot of teams in different leagues (simulation, small-size, middle-size, four-legged, etc.) play against each other. After such a competition, the participating teams release their research which can be studied and used by other (new) teams. This process results in better robot soccer results year after year.

The UT (University of Twente) is new to the field and is trying to set up a team to play in the middle league of the FIRA[1] MiroSot competition. This robot soccer team is called Mi20[2] (Mission Impossible Twente). In this competition five small robots form a team. By participating in this league, the UT hopes to gain a valuable insight into AI (Artificial Intelligence), multi-agent systems, etc. which is needed to let a team of robots play a match of soccer. The attained knowledge can then be used by and used in other projects. For information about FIRA game rules which apply in a match of robot soccer, see the FIRA regulations[3].

1.1.1. Mi20 progress

The Mi20 team has currently almost finished constructing their robot soccer team. Figure 1.1 on the following page describes the distributed system used by the Mi20 team to accomplish a working robot soccer team. The red highlighted system (number one) in figure 1.1 contains a global vision system which determines all individual robot and ball positions and headings[4], called vectors[5], from the soccer field it observes. These vectors are sent (in a so called snapshot[6]) to and analyzed by system number two. This system determines the strategies and actions to be taken by individual Mi20 robots. Next, these robot actions are sent to and translated by system three which calculates robot wheelspeeds which will maneuver the Mi20 robots on the soccer field. These wheelspeeds are sent to system one which, in turn, sends those wheelspeeds to the Mi20 robots on the soccer field via a radio frequency link.

In the meantime, the opponent team is also maneuvering its robots to new positions on the soccer field using a (similar) control system of their own. These new opponent robot vectors, those of the Mi20 robots and the new ball vector are then again retrieved by the global vision system after which the process starts anew. This entire cycle will be completed 30 times per second[7].

1.1.2. Need for a simulator

Systems two and three in figure 1.1 use a sophisticated AI (Artificial Intelligence) control system to determine robot actions and to control the Mi20 robots respectively. To test these systems and to train the AI components, a simulator, currently provided by the FIRA from the FIRA SimuroSot league[8], is being used. Such a simulator will replace system one and the soccer field containing all robots and the ball entirely (see also the red highlighted system in figure 1.1). In order to accomplish that, the simulator will have to comply to the communication interface which is described by the Mi20 team. This interface is described in detail in paragraph 3.6. Suffice to say here, snapshots have to be sent and wheelspeeds have to be received by a simulator.

1. FIRA, or Federation of International Robot-soccer Association, see reference [W2].
2. See the Mi20 homepage; reference [W1].
3. FIRA MiroSot Middle League rules can be found in reference [B1].
4. Headings indicate the orientation of the robot or ball according to the x axis of the soccer field.
5. Mathematical vectors used in the MiS20 contain x and y positions, a heading and timestamp.
6. A snapshot contains vectors for the ball and the robots of both teams.
7. The camera used in the global vision system has a framerate of 30 frames per second.
8. The FIRA SimuroSot league is the simulation league of the FIRA. Only AI is used here.

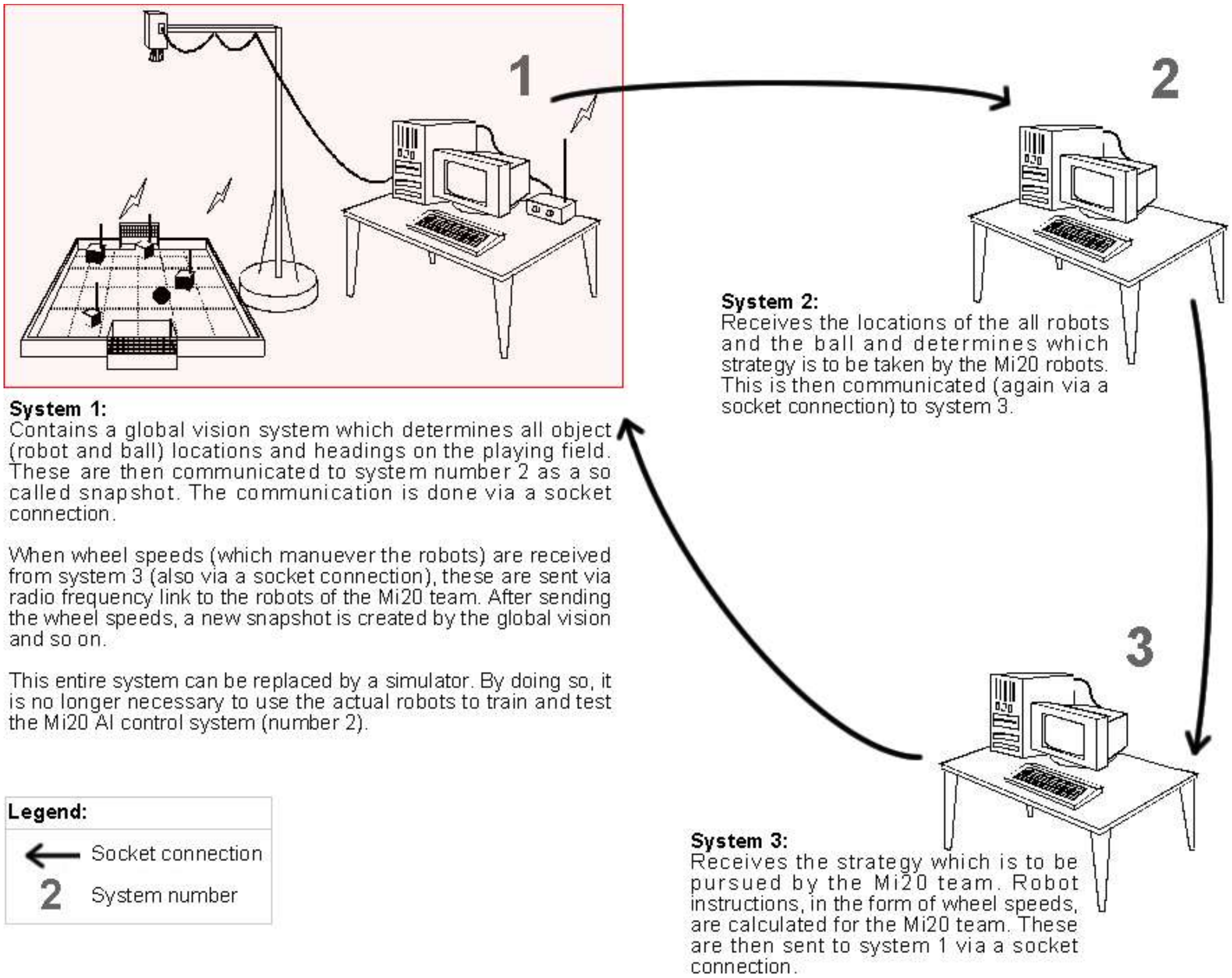


Figure 1.1. The overall system system used by the Mi20 robot soccer team

The FIRA simulator, which is currently used, does not meet all requirements set by the Mi20 team[9]. It also cannot be changed to meet those requirements since it is not open source. Therefore, a different simulator has to be found or created for use in the Mi20 robot soccer project.

1.1.3. Alternative simulator

The FIRA simulator is not the only robot soccer simulator available for simulating robot soccer matches. Besides the FIRA robot soccer initiative there is another initiative, called RoboCup. RoboCup also has a simulation league for which a simulator is used. This simulator however, is set at two teams of 11 robots each playing a match of robot soccer. It is open source so it is possible to adjust it to meet the requirements stated by the Mi20 team. However, the RoboCup initiative differs to such an extent from the FIRA initiative that, doing so, would result in almost completely rebuilding the RoboCup simulator.

Besides these two robot soccer simulator programs, there are no other publicly available robot soccer simulators. Also, the creators of the FIRA simulator will not release their source code when asked. The only solution left is to create a new robot soccer simulator. The requirements for this new simulater are stated in the requirements chapter[9].

[9]. The Mi20 requirements are described in chapter 2.

1.2. Project goal

A new simulator for use in the Mi20 robot soccer project will have to simulate the objects (robots and ball) in an approximately correct way. Otherwise, the Mi20 AI control system (systems two and three in figure 1.1) will learn to apply certain strategies which will not work when controlling the real robots instead of the simulator. We have named this new simulator “MiS20”, which stands for “Mission Impossible Simulator”.

So, summarizing, the goal of our project is:

> *Create a new realistic simulator for a five against five robot soccer match played according to the FIRA MiroSot middle league game rules. The robots and the ball must simulate their real counterparts in an approximately correct way.*

This project goal leads to a research question which we will need to answer in this project:

> *When does the level of simulation of the robots and the ball reach the required level of an approximately correct simulation; which physical aspects need to be taken into account?*

1.3. Project approach

This paragraph describes the approach we used to accomplish the project goal. First we will describe the schedule we used for this project. This is followed by our utilization of risk management and how we used an iterative project approach. In conclusion, we will state our use of quality management.

1.3.1. Schedule

At the beginning of the MiS20 project we created a schedule which contained all relevant deadlines. This schedule can be found in appendix A. We had little difficulty reaching those deadlines in time. However, some documents, such as our design document, were altered after the first release on the deadline date.

1.3.2. Risk management

We used basic risk management to overcome unexpected setbacks. An extra week was planned in case of illness. CVS[10] was used to ensure that as little loss of data as possible. We did not apply extensive risk management strategies such as determining risk weights for each set deadline because it would result in too much overhead and because we have too little experience which is a risk in itself. Further, we worked using iterations. This iterative project approach gradually expanded the MiS20.

1.3.3. Iterations

Our first iteration consisted of creating a simple prototype program. This only implemented the basic data model and a relatively simple GUI[11]. Information from the data model was only displayed to the user.

The second iteration expanded on the first one by adding the communication with the Mi20 control system. Also, data logging to XML files was created[12].

The third iteration expanded even further on the previous two. An XML parser was written to retrieve data which has been logged to file. Also, the GUI was updated with a 3D view of the soccer field and with user controls to control a match. We also researched collision detection and collision handling techniques.

The fourth, and final, iteration included mainly performance boosts to increase the MiS20 program's speed. The collision detection and collision handling techniques found in the previous iteration were implemented in the simulator. Also, we began researching and implementing kinematic and dynamic object models which can be used in the Mission Impossible Simulator. After this iteration we were able to simulate an entire robot soccer match.

[10]. See reference [W9].
[11]. GUI, or Graphical User Interface.
[12]. MiS20 program components are derived in the chapters two through five.

1.3.4. Design methods

In this iterative process three design methods have been used to create a project design; NIAM, OVID and UML[13]. NIAM models the static data whereas OVID described a user interface seen from the users point of view. UML then models the results from NIAM and OVID. The resulting UML design was implemented using Java, Java3D and JNI. The created source code complies to a standard as seen in our implementation document[14]. These design methods ensure that MiS20 may be easily expanded.

1.3.5. Quality management

To ensure the quality of our software and documentation we have created templates to which all source code and documents will be created. The source code template can be found in our implementation document[14]. We also utilized reviewing of source code and documentation. Source code was reviewed by ourselves. The documents we created were reviewed by UT personnel, our Saxion tutor and peers from the Saxion College.

1.4. Document structure

Chapter 2	states and explains the requirements regarding the MiS20.
Chapter 3	describes the analysis made and design created for the MiS20 robot soccer simulator, all steps of the analysis and design are explained.
Chapter 4	states the implementation phase of the simulator. Also, implementation difficulties and their solutions are explained.
Chapter 5	displays the test methods used for testing the simulator. The test results are also described in this chapter.
Chapter 6	contains all project results.
Chapter 7	states the project conclusions.
Chapter 8	describes the recommendations which can be made regarding this project.
Chapter 9	contains our the personal reflection on the project.

[13]. See glossary and references [B4], [B6] and [B9] for more information.
[14]. See reference [B7].

2. Requirements

This chapter will state and explain all requirements the MiS20 must comply to. They have been separated into different groups; system, user, implementation and optional. The requirements in this chapter have been derived by discussing with the future users (the Mi20 team) and by examining the existing FIRA simulator.

2.1. System

This paragraph states the general system requirements. The MiS20 has to be integrated into the existing Mi20 system, it will have to simulate an entire match in an approximately correct way and it needs to be able to store logged data to and read logged data from disk.

Also, the MiS20 must replace system one in figure 1.1. In order to perform that task, the simulator will have to generate snapshots at an interval of at least 33 milliseconds. This interval can be derived from the global vision system used by the Mi20 team. This system uses a camera which has a framerate of 30 frames per second. This results in 33 milliseconds per frame.

2.1.1. Interface

MiS20 will be a part of the distributed Mi20 system. As seen in figure 1.1, the MiS20 will replace the system containing the global vision component and the actual playing field (number one) entirely. Since that system communicates with the remaining distributed Mi20 systems (numbers two and three in figure 1.1) the simulator must use that set interface. This interface with the Mi20 distributed system is described in our design document[1].

2.1.2. Approximate correct simulation

As seen in paragraph 1.2, the MiS20 will have to simulate the robots and the ball in an approximately correct way. Therefore, a dynamic and kinematic model for the robots and ball has to be created. This model uses various physical aspects such as friction and acceleration as well as collision results; what will happen when a robot collides with the ball, another robot or a wall? Such an approximately correct way of representing a robot or ball is required because the AI system would learn to apply different strategies as it should do when using the real robots.

2.1.3. FIRA regulations

Not only the robots and the ball need to be simulated, but also the match itself. To simulate a match correctly it must be possible to simulate the application of the rules the FIRA regulations state[2]. In a real match, a human referee applies those rules. Hence, it must be possible to referee a match.

2.1.4. Logging

All data generated during a robot soccer match must be logged to disk. This match data can be read from file later on to review the match. Also, it must be possible to read from, write to, edit and delete from disk certain fixed locations (called snapshots) for the robots and the ball.

It is necessary to log matches and snapshots for reuse. A match can be (re)played in the simulator to evaluate where things went wrong. Snapshots can be used by the referee to position the robots and ball in a goal kick situation for example. Also, snapshots can be used to test certain decisions from the AI control system as described in figure 1.1.

2.1.5. Expansion

The Mission Impossible Simulator must be designed and implemented in such a way that it can easily be expanded upon. This is necessary because it will most likely be expanded in various ways.

[1]. See reference [B3].
[2]. See reference [B1].

2.2. User

This chapter describes the requirements to which the (GUI of the) simulator must comply to regarding the user's interaction with the system and vice versa.

2.2.1. Object representation

The soccer field must be displayed in 3D. The field, robots and the ball must have correct colors, size and aspect ratio between objects. Also the data for each of the objects in the match must be displayed in an unambiguous way. The reason for this 3D representation is to enable simulation of robot vision and other, not yet applied, technologies.

2.2.2. Options

A user must be able to set various options in the simulator which will enable him or her to test the Mi20 AI control system. These options include: collision detection on/off, application of FIRA rules on/off, ability to switch between various control modes per team.

The latter requires some explanation; it must be possible to change the way a team is controlled (where it receives its wheelspeeds from). This will enable the possibility of letting a team play against itself and against human controlled robots (via joysticks).

2.2.3. Stop and resume

A user must be able to stop and resume the simulator at any time he or she chooses. Whilst the simulator is stopped, it can be manipulated by the user: robots can be repositioned, another snapshot can be loaded, etc.

2.2.4. Match data

A match consists of two teams and a ball. These teams consist, in turn, of a set of robots. The match objects (the robots and the ball) are represented to the user as described in paragraph 2.2.2. A match also has an elapsed time and a score per team. Both of these values should be displayed at all times. These values must be sent every five seconds to the Mi20 system.

2.2.5. Manual referee

As described in paragraph 2.1.3, the MiS20 must have the ability to apply FIRA regulations to a match. Since an automated referee would take a lot of time and effort to construct, the most reachable solution for the requirement as stated in paragraph 2.1.3 is to let the user referee a match. A FIRA referee has to be able to call the following situations according to the FIRA game rules: free ball, free kick, goal kick, penalty kick, kick off and goal scored. Also, he or she must be able to pause a match at any given moment.

2.2.6. Messaging

The user must be provided with messages stating which action is required from the user. These messages can be divided into two different groups: not important (displaying a line to the user which contains the current system state) and important (user will be confronted with this message using a pop up window for example).

2.2.7. Objects

The objects (the ball and all robots) in a match must be manipulatable. A user must be able to reposition an object in the soccer field. Also, a user must be able to apply a new heading to an object.

2.2.8. Logging

As described in paragraph 2.1.4, match data and snapshots must be logged to disk. A user must be able to administrate those files using the simulator; file deleting, storing, reading and editing (only for snapshots).

2.3. Implementation

This chapter will describe the implementation requirements. We must comply with these requirements while programming.

2.3.1. Language

The simulator must be implemented using Java and Java3D. The reason for this is that it can easily be expanded upon easily by UT students among others.

2.3.2. Error handling

MiS20 should be programmed in such a way that when errors occur these are handled correctly: the simulator should not crash but display a message to the user and display a detailed error message to the command line indicating the source and reason of the error.

2.3.3. Assertions

Assertions are to be used to ensure object data has been set or altered correctly. These assertions should be removed in the final version of the Mission Impossible Simulator since they cause an unnecessary overhead.

2.4. Optional

This chapter describes the optional requirements which will only be implemented in the simulator if there is any time left. However they should be used when designing the new simulator system to be able to expand upon the simulator we will create. This should ease expansion of MiS20 by other students.

2.4.1. Multiple camera vantage points

The user must be able to switch between different camera vantage points in the 3D representation of the robot soccer field. A few examples of these vantage points are:

- Top-down (default, views the entire field to top-down as if it were the real global vision system);
- Free camera (ability to move the camera freely through the 3D soccer field representation);
- Object pursuit (the camera follows an object around the field).

2.4.2. Automated referee

At first the simulator will be equipped with a manual referee option. This requires user interaction (a user should be applying the FIRA rules). The logical course of action for our simulator is to have an automated referee which can call situations automatically. This can be used to train the Mi20 AI control system even when no user is present (during weekends for example). Further, when this option has been implemented an option must be added to turn it on and off.

3. Analysis and design

This chapter describes the analysis of the MiS20 as well as the design created for it. The standard Model View Control design principle was used to design the Mission Impossible Simulator. This chapter is structured in much the same way.

First, the “old” FIRA simulator is described with its shortcomings. Second, the model is analysed and designed using NIAM[1]. Third, the user interactions (control) with the MiS20 are designed using UML[2] use cases. Fourth, the view is designed using the FIRA simulator GUI as a base and by using OVID[3]. Fifth, the communication with the existing Mi20 components is designed using UML. Finally, all components are integrated in one overall UML design which can be implemented by a programmer.

3.1. FIRA simulator

The FIRA simulator was created by a professor and a few students of the School of Information Technology of the Griffith University in Australia[4]. This simulator has a number of flaws which make it not entirely suitable for use in the Mi20 robot soccer project. A list of these flaws or shortcomings:

- Manual action is required to exit replay mode, as well as in various other menu's. This requires constant human user interaction.
- The simulation, provided by this simulator, is not precise enough. Objects are not modelled using a kinematic and dynamic model which approximates the real world as best as possible. Therefore, the AI control system will not learn well enough by using this simulator.
- The FIRA simulator is not open source, which means that it cannot be changed, expanded upon etc.
- Simulation settings and generated match data cannot be saved to disk directly. This means that there can be no reuse of generated match and snapshot data.
- No object positions can be loaded (from file) into the simulator to test or train a specific setting (for example a penalty kick). This has to be done manually for each try.
- Robot representations are not unambiguous; robots are to be identified using a colored patch. This may very well result in unnecessary user errors.
- No FIRA regulations[5] can be applied since no referee option (manual or automated) is present.

The remainder of this chapter will use the shortcomings of the FIRA simulator as stated above and the requirements as stated in chapter two to design the Mi20 simulator. The FIRA simulator also incorporates a number of properties which have proven very useful and will be required in the new simulator. These are:

- A 3D view of the soccer field.
- Use of various robot control methods, for example the possiblity to control both teams using the same (AI) control system.
- Extensive help messages to the user.

3.2. Mission Impossible Simulator

MiS20, the robot soccer simulator we will construct in our project, will resolve the shortcomings of the FIRA simulator as well as using the useful aspects of it. Since we will use the MVC design principle to construct MiS20, it will consist of three separate components; model, control and view. MiS20 will have to communicate with the existing Mi20 control system via a set communication interface. The four resulting components of MiS20 will be explained in the remainder of this chapter. The model component will include data storage and updating vector data. The control component will describe which interactions are possible with the MiS20. The view component will include the design of the graphical user interface. Finally, the communication interface will describe the exact interface with the Mi20 control system.

1. NIAM, or Natural language Information Analysis Method, see reference and glossary [B5].
2. UML, or Unified Modelling Language, see reference [B6] and glossary.
3. OVID, or Objects, Views, and Interaction Design, see reference [B9] and glossary.
4. From the help file of the FIRA robot soccer simulator, for more information see reference [W2].
5. See reference [B1].

3.3. Model

NIAM constructs a data structure which can be used to create a database, UML objects etc. First, a world description is made which describes all aspects of the robotic soccer “world” in detail. Second, objects are distilled from this description. Third, the way objects in the robotic soccer world (found in the previous step) interact with one another is described. All restrictions on these interactions are taken into account. Finally, the resulting data structure is displayed in a so called Information Grammar Diagram or IGD. This IGD states all steps as described above.

This paragraph explains the steps taken to create a data structure for the MiS20. Our entire NIAM analysis is described in all detail in our design document[6]. We will not describe the entire NIAM analysis here.

3.3.1. A robot soccer match description

A robot soccer match is played by two teams, consisting of five robots each. Each team has a color, either yellow or blue, which is determined prior to each match by a match referee. The goal is the same for both teams: score as many goals as possible to win the match. The match lasts ten minutes, five per half. After each match half the teams switch ends field halfs.

The time will be halted whenever the referee pauses the match. This can be done for various reasons, a foul play has occurred, a goal has been scored etc. If there is a draw after the ten minutes of official play time, the game will be continued for three additional minutes in which a sudden death (or golden goal) scheme is applied. If there still is a tie after sudden death, penalty kicks will be taken; three per team, until there is a winner[7].

Each team is controlled by three human players (coaches). These people cannot and may not interfere with their team during play. Two substitutions are allowed during game time, however at half time unlimited substitutions may be made. Further, it is the referee's task to call fouls in the game, a few of which are: deliberate colliding with an opponent robot, pushing the opponent goal keeper in its goal, attacking with more than one robot and defending with more than one robot[7].

A match contains a set of objects. These objects have a vector[8] in the soccer field and are identified by a number. Also, each of these objects contains a list of previous positions. These objects can be divided into two groups; robots and balls. Since there is only one ball, the other objects in a match are solely robots. Robots are part of one of the two teams playing in a match. Such a team is identified by a number. Each team contains five robots. The team color (yellow or blue) identifies these robots. Each robot is, not necessarily, identified by an individual color and id number. Further, each robot has two wheels (left and right) which each have an individual speed and acceleration, the latter being equal in most cases.

3.3.2. Objects

The objects which NIAM distills from the world description given in paragraph 3.3.1 can be represented in an IGD[9]. Most of the time, such objects are identified by a name or a number (like the robot for instance). These are called "normalised" objects in NIAM. Normalised objects can also be identified by other objects, indicating a parent-child relationship. The objects found from paragraph 3.3.1 are fully stated in our design document[6]. Figure 3.1 on the following page gives the most important components. These represent a match having two teams (consisting of five robots each) and a ball.

[6]. See reference [B3] for the MiS20 design document.
[7]. The FIRA regulations are stated in reference [B1].
[8]. Mathematical vectors contain a x and y position, a heading and a timestamp. *Not* to be confused with a Java *java.util.Vector* class
[9]. IGD; Information Grammar Diagram, see reference [B5] and glossary.

Figure 3.1 describes that a match has a name and date on which it is played to identify itself. A team and an match object (called a SimObject) are identified by a number. The ball and robot objects are identified by a SimObject object. This indicates a parent-child relationship; SimObject is a parent of a ball object for example.

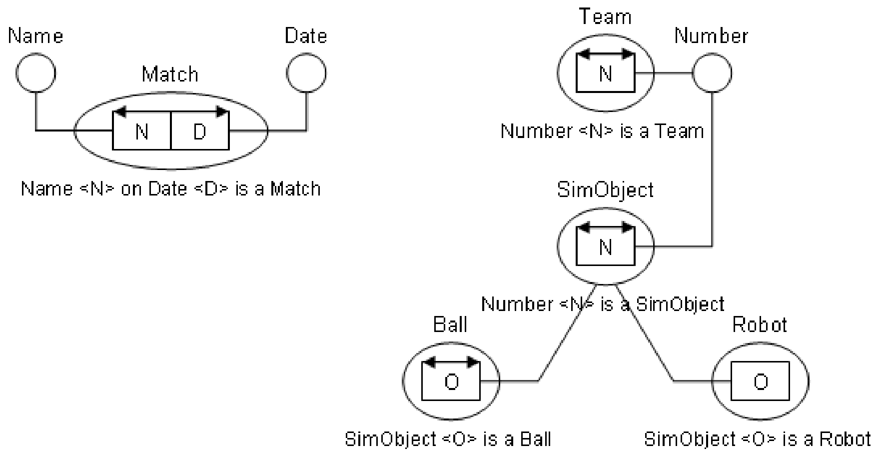


Figure 3.1. IGD – normalised objects

3.3.3. Relationships

The objects described in figure 3.1 have relationships between them. Those relationships indicate the way these objects interact with one another. Figure 3.2 states the simplified objects from figure 3.1 with those relationships. These relationships are explained on the following page.

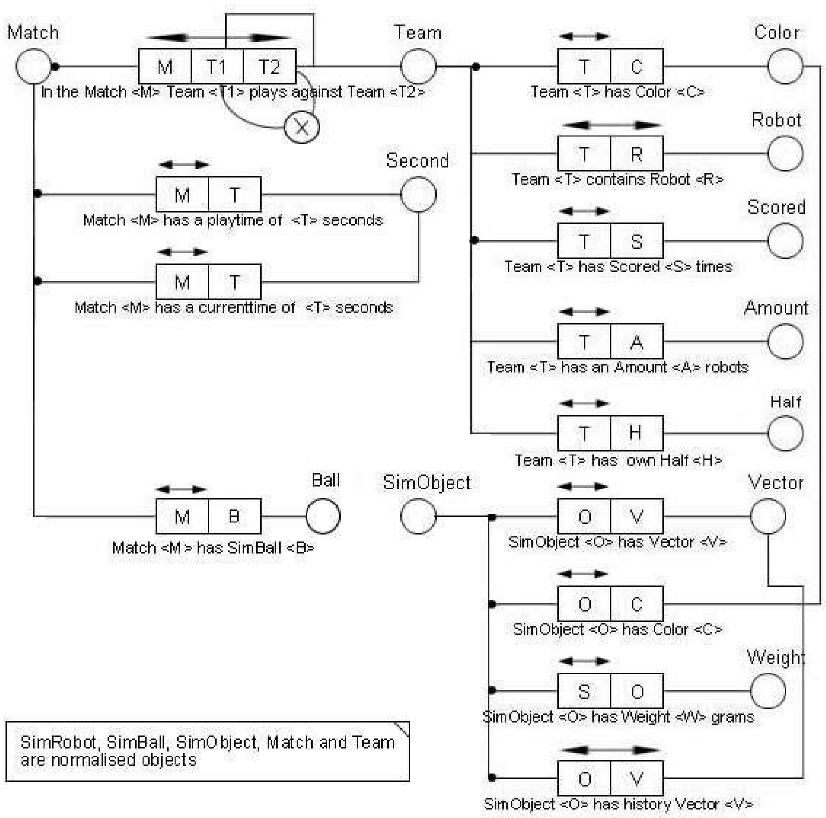


Figure 3.2. IGD – object relationships

The match object contains two different teams which will play against each other. It has a playtime and a currenttime, the first indicating the entire time a match should last and the latter indicating the current time of the match. Finally, a match has a ball the teams of robots will play with.

The teams in a match each contain five different robots. Each team has a unique color (either blue or yellow) which will identify it. Also, a team keeps track of its own set of goals it has scored as well as the half it is playing from currently (either left or right).

The robots in a team, as well as the ball, are child objects of the SimObject object. Such a SimObject keeps track of where it has been during the match via a list of vectors. The last vector in this list being the current vector position of that SimObject. A SimObject has a weight in grams which is to be used in the kinematic and dynamic models of the robots and the ball.

3.3.4. Storing data

The requirement in paragraph 2.1.4 states that generated match data and snapshots, indicating FIRA situations such as free ball for example, are to be logged to file. This data can be saved using various file layouts:

- XML, the new standard for communication and saving data;
- A new, selfmade, file layout with tags etc;
- A database;
- Java Property files, a method to save data to file using Java.

These methods all require some kind of file parser/writer. The latter, Java Property files, already incorporates such a file parser/writer which would result in less work. However, since XML is being used more and more frequently and the possibility for the Mi20 project to reuse the XML generated by the simulator the XML option would be the better choice. There are ready made XML parsers available on the internet as well as at the UT. The use of a self made file layout will result in too much work since a file parser will have to be created from scratch. Finally, the use of a database results in too much overhead which also rules out this option.

Two XML layouts have been designed which incorporate all information regarding snapshots and matches respectively. Only the basic information needed in these layouts is being stored. The design document[10] describes these layouts in great detail.

3.3.5. Updating data

When a robot soccer match is being simulated the simulator (in our case, MiS20) will receive wheelspeeds from the Mi20 control system. These wheelspeeds are translated into new vectors for each robot in the match. The ball also gets a new vector depending on its speed and possible collisions.

Updating these vectors is done 30 times per second[11]. The latest known wheelspeeds for each robot are used to update the vectors. These new vectors are then added to the vector history list which we described in paragraph 3.3.3. The current vector for an object is the last vector in the vectorlist.

Since it would be useless to update the object representation in the MiS20 GUI when no changes have been made, this will only be done when a new vector has been set for an object (robot or ball). The GUI will then update its representation of that robot or ball according to that new vector.

[10]. For the MiS20 design document, see reference [B4].
[11]. Identical to the framerate the camera used by the Mi20 global vision system.

3.3.6. The soccer field mathematics

The soccer field which will be represented in the MiS20 will have two axes which are used for all robots and the ball. Figure 3.3 represents the axes system which is used in the Mi20 control system. Since we will need to communicate with that system it is only logical to use those settings ourselves.

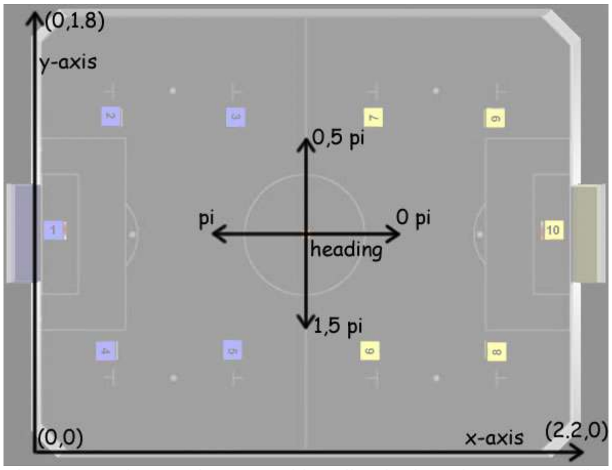


Figure 3.3. The used axes and heading in the MiS20 soccer field

3.3.7. Robot wheelspeeds

The robots have two wheels, each of which has a different wheelspeed. These two wheelspeeds enable a robot to turn and thereby maneuver on the soccer field. The Mi20 control system uses so called PWM or Pulse Width Modulation[12] to represent these wheelspeeds. This wheel PWM value indicates the current wheelspeed in millimeters per second (mm/s).

3.3.8. Collisions

When the robots maneuver on the soccer field in a match they will undoubtably collide with one another and with the ball. MiS20 must be able to simulate a match of robot soccer according to the project goal in an approximately correct way[13]. To accomplish such a simulation the collisions between objects will have to be simulated as well. In the game industry a lot of different techniques have been developed to detect and handle collisions between 2D and 3D objects. Equations used in the chapter have been found in reference [B13], [B15], [W13], or derived from known formulas.

There is, however, no need to detect collisions in 3 dimensions since the robots can only maneuver in two. Also, the robots used in the FIRA MiroSot leagues are in fact simple cube shaped objects as is illustrated in figure 3.4. This rules out the need to detect collisions in the remaining third dimension because the ball cannot for example bounce upwards on a robot.

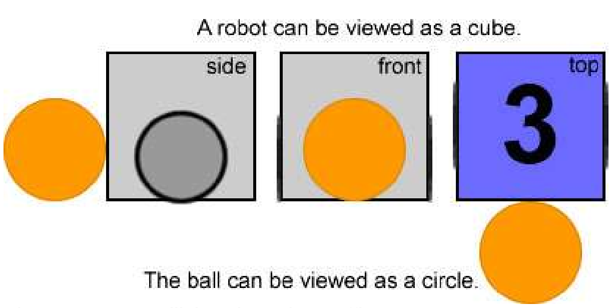


Figure 3.4. 2D collision detection suffices

[12]. The Mi20 robots were bought from the University of Dortmunt. Wheelspeeds were called PWM there.
[13]. See paragraph 1.2.

3.3.8.1. Detecting

Collisions have to be detected between any of the ten robots and the ball. These objects can also collide with the wall. Each object has to be compared with all the others to detect a collision. This results in having to perform roughly

$$N^2 \tag{Eq. 1}$$

comparisons[14]. However, there is no need to check a collision seen from both objects in the same collision. If object two collides with object three, object three will automatically collide with object two.

Collision detection is a very costly[15] procedure to perform. This cost will therefore need to be reduced as much a possible. To accomplish this, the detection algorithm(s) will have to be chosen to suit the task in MiS20 best. There are a lot of different collision detection techniques which can be used. Almost all of which originate from the gaming industry. A few of these collision detection techniques are[16]:

- Axis Aligned Bounding Boxes (AABB): using a bounding box around the object which encompasses the entire object no matter what its orientation. This bounding box is aligned with the axes system. See figure 3.5 for an illustration;
- Oriented Bounding Boxes (OBB): similar to AABB detection only the bounding box is aligned with the objects local axis system which results in a closer fit compared with AABB;
- Bounding sphere: similar to AABB and OBB, a bounding sphere is used to encompass the object, see figure 3.6 for an illustration;
- Binary Space Partitioning (BSP) trees: the 2 (or 3) dimensional “world” is divided into different segments (partitions) in which objects are contained. When two objects are in different partitions they cannot collide.

The latter, BSP trees, will perform well when objects are far apart and do not collide. When objects are close to each other BSP trees are very performance costly which will turn it into a major bottleneck. BSP trees are therefore not particulary suited for use in MiS20. The other three methods can be used however.

Since collision detecting is very CPU costly, the best method to detect collision is to divide the detection into two (or more) layers of precision[14]. First we will detect if a collision might be possible between two objects using a relatively inaccurate but fast algorithm. If a collision might be possible, a more accurate test will be performed to detect if the collision actually has occured. If this test also passes, a collision will have occured which will be handled as is described in paragraph 3.3.8.2. This approach will result in better performance results. The second test can itself be expanded with a even more precise collision detection algorithm if need be.

We will use AABB collision detection in the first level of detecting collisions. This is less costly compared with the OBB and bounding sphere algorithms. The MiS20 AABB detection results in bounding boxes which size equals to the diameter of the robots. Using this (set) size, the object will always be included in the AABB.

Further, our AABB detection can be divided into two steps. First we check if an object can collide using the difference between x axis locations of the two objects. If this difference is already too great to rule out any collision, the y axis difference will not have to be checked. This will reduce performance of the collision detection algorithm by 50% in most cases. Equation 2 illustrates the way the x and y axis can be checked.

$$\begin{aligned} &x_a - x_b > AABB\,side_{length} \\ &y_a - y_b > AABB\,side_{length} \\ &where\ AABB\,side = \sqrt{2} \cdot CUBE\ side \end{aligned} \tag{Eq. 2}$$

[14]. Gamasutra, advanced collision detection, see reference [W5].
[15]. Costly regarding CPU use.
[16]. See reference [W10].

OBB detection relies on having to calculate a local axis system for each object and then determining axis differentials between objects. Bounding sphere collision detection is more CPU costly since it requires both x and y locations for each object to be used in determining the distance between two objects. The AABB and bounding sphere detection algorithms are illustrated in figure 3.5 and 3.6 respectively.

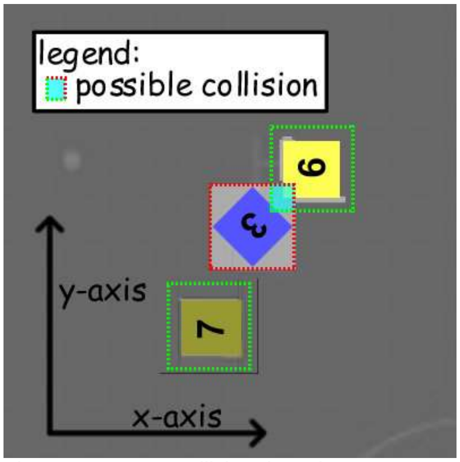


Figure 3.5. AABB collision detection.

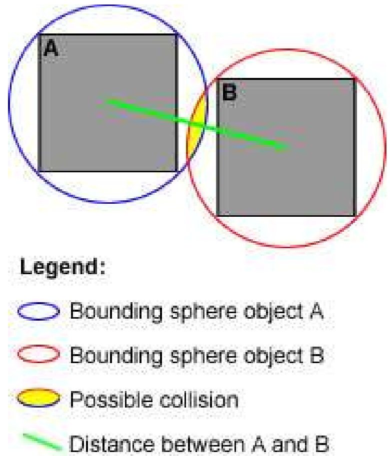


Figure 3.6. Bounding sphere collision detection.

The second level of detection consists of two techniques, one per shape (sphere or square). The OBB algorithm would be imprecise for elaborate shapes. However, the robots can be viewed as being OBBs themselves. We can therefore use OBBs to detect collisions between robots and robot-wall collisions. Collisions with the ball can be detected using a bounding sphere representation for the ball. The OBBs and the bounding sphere can be used simultaneously to conclude the second level of collision detection.

Figures 3.7 and 3.8 illustrate the two levels of collision detection used in MiS20. When a collision might occur, the corner points of the objects involved will be tested to see if such a point resides in the other object. If so, the line(s) that point is part of will be handed to the collision handling algorithm which uses that information to react on the collision properly. In figure 3.7, these lines are AB and BC of object 6, and EF of object 3. Figure 3.8 illustrates a collision between a robot and a ball. CD of the robot is the colliding line. A collision between the ball with a wall and a robot with a wall is handled in a similar manner as is illustrated in figures 3.7 and 3.8.

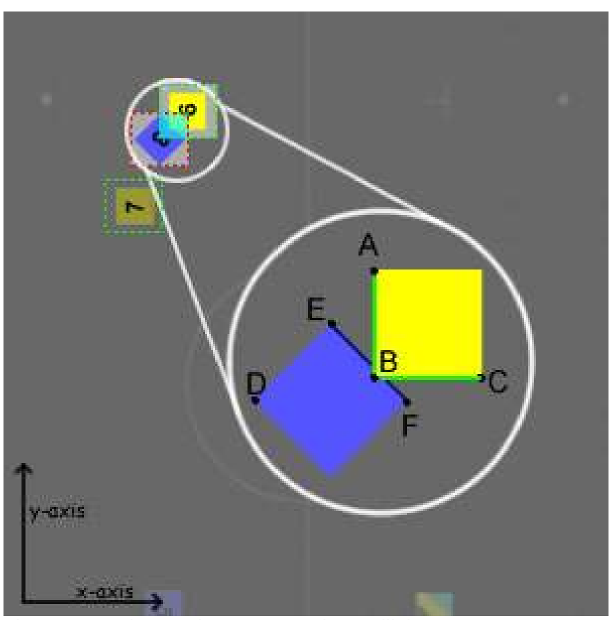


Figure 3.7. MiS20 robot versus robot collision

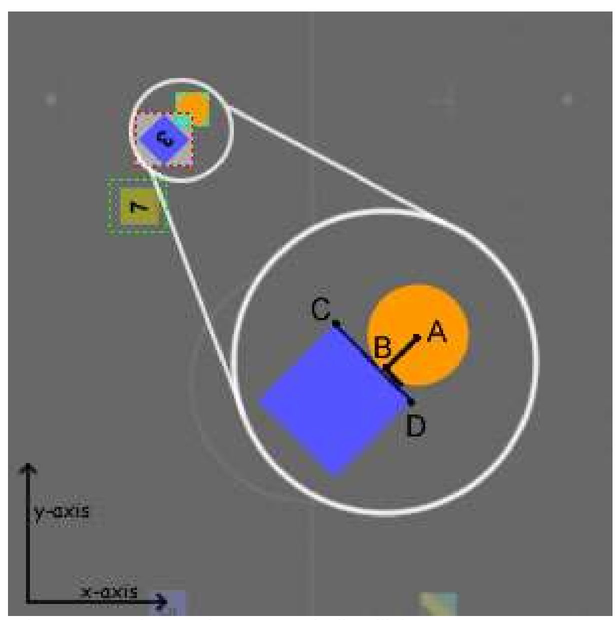


Figure 3.8. MiS20 robot versus ball collision

The time between two vector updates is about 33 milliseconds. This means that collisions in between these time intervals have to be detected. The maximum robot velocity[17] is 2,0 ms^{-1}, and with AABB collision detection, a box will be drawn around both objects. The box for the ball will be the same size as the box for the robots. The dimension of such a box is:

$$\begin{aligned} &half\ cubesize = 0{,}0375\,m \\ &robot\ radius = \sqrt{2} \cdot half\ cubesize \\ &box\ length = box\ width = 2 \cdot robot\ radius \approx 0{,}106\,m \end{aligned} \quad \text{(Eq. 3)}$$

No collision predictions will be needed in the time between two intervals; 0,0333 s. A predicition would be needed only if the distance traveled by two objects, which would normally collide, is larger than twice the AABB size; 0,212 m. The accumulated speed of a robot and the ball involved in a collision would need to be 0,212 m / 0,0333 s = 6,36 m/s. Since the maximum speed of the robot is 2,0 m/s, the ball would have to move 4,4 m/s. This speed is not obtainable by the ball in a robot soccer match[18]. We can therefore conclude that the AABB collision detection algorithm will detect all possible collisions.

3.3.8.2. Handling

When a collision has been detected, the proper action has to be taken. This “proper action” depends on the kinematical and dynamical representations of the ball and robots. For example, when two robots collide their individual impact speeds, weights, orientations etc. will all effect the resulting robot vectors and speeds after the collision. Because of the difficulties of robot versus robot collision handling, a rather simple handling will be used. When two or more robots collide with each other, they will not drive through each other, but will come to a stand. This robot versus robot collision handling will suffice for a basic collision handling between robots.

In order to handle the collisions, a new coordinate system will be added. The normal axis is in the direction of the line of collision and the tangential axis is perpendicular to n.

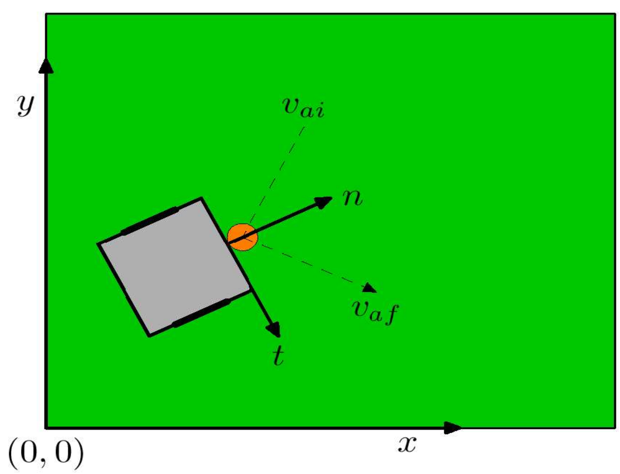


Figure 3.9. A new co-ordinate system

The collision handling will be done by using physic formulas[19]. The following equations will be used in order to simulate realistic collisions:

$$\begin{aligned} &m_{object1} \cdot v_{\substack{object1\\initial}} + m_{object2} \cdot v_{\substack{object2\\initial}} = m_{object1} \cdot v_{\substack{object1\\final}} + m_{object2} \cdot v_{\substack{object2\\final}} \\ &\frac{1}{2} \cdot m_{object1} \cdot v^2_{\substack{object1\\initial}} + \frac{1}{2} \cdot m_{object2} \cdot v^2_{\substack{object2\\initial}} = \frac{1}{2} \cdot m_{object1} \cdot v^2_{\substack{object1\\final}} + \frac{1}{2} \cdot m_{object2} \cdot v^2_{\substack{object2\\final}} \end{aligned} \quad \text{(Eq. 4)}$$

[17]. From the Mi20 robot specifications.
[18]. The maximum ball speed cannot exceed 2,82 m/s as can be calculated using equation 5 and match data generated by the Mi20 team.
[19]. See reference [B14].

In equation 4, m is the mass and v is the velocity. Using a coefficient of restitution e[20], the new velocities can be calculated resulting in equation 5, where n is the normal vector.

$$v_{\substack{object1\\final}} n = ((e+1)\cdot m_{object2}\cdot v_{\substack{object2\\initial}} n + v_{\substack{object1\\initial}} n \cdot (m_{object1} - e\cdot m_{object2}))/(m_{object1}+m_{object2})$$
$$v_{\substack{object2\\final}} n = ((e+1)\cdot m_{object1}\cdot v_{\substack{object1\\initial}} n - v_{\substack{object2\\initial}} n \cdot (m_{object1} - e\cdot m_{object2}))/(m_{object1}+m_{object2}) \quad \text{(Eq. 5)}$$

The last step consists of transforming the n - t coordinate system back into the x - y system. The coefficient of restitution e[20] can be determined by equation 6 and will be calculated according information of played matches[21].

$$e = \frac{v_{\substack{object2\\final}} - v_{\substack{object1\\final}}}{v_{\substack{object2\\initial}} - v_{\substack{object1\\initial}}} \quad \text{(Eq. 6)}$$

3.3.9. Kinematic models

Our project research question states when these kinematical and dynamical object models will be sufficient to simulate a robot soccer match in an approximately correct way. Equations used in the chapter have been found in reference [B13], [B15], [W13], or derived from known formulas. The ball and robot will, logically, have different object models. However, both models will have to encompass friction with the soccer field, object weight and object size. The equations below are used to determine speeds of an object (either ball or robot wheel and robot) taking friction with the floor into account.

When the robots and the ball move on the field, as a result of wheelspeeds or a speed which they were given after a collision, they will also have a kinematic model. This model represents the way they maneuver on the soccer field. A number of things have to be taken into account when creating such a model. First of all, friction. Friction with the ground will slow an object down. The same will go for air friction. However, the latter may not be needed since its low value.

3.3.9.1. The ball

The ball used in a FIRA MiroSot middle league robot soccer match is an orange golf. This golf ball is round of course, but it also contains a lot of dents distributed across its surface. These balldents make that we will have to consider if we will simulate the ball as a perfect round sphere or if will simulate it as an elobarate object. The latter would result in only a little deviation on the trajectory followed by a perfect sphere across a plane[22] at the the cost of a lot of CPU usage. The effort is not worth the benefits.

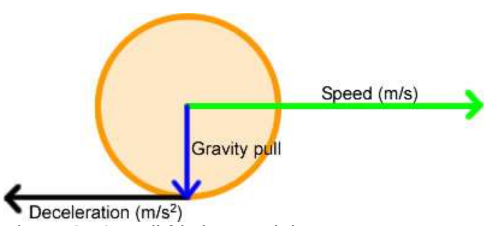


Figure 3.10. Ball friction model

Figure 3.10 illustrates the friction model which is to be used in the MiS20. Since the ball is to be considered as a perfect sphere, it will also have its weight distributed evenly. This places the center of gravitational pull in the center of the ball. This pull will result in a friction with the floor which results in a set deceleration for the ball when no collisions occur. To determine this friction deceleration constant, the properties of the ball have to be filled in equations 7 and 8.

[20]. The coefficient of restitution models the loss of kinetic energy. If e = 1 you have a perfectly elastic collision and e < 1 corresponds to a less than perfect collision.
[21]. See chapter 6 for the value of the coefficient of restitution.
[22]. This slight deviation has been observed in an actual soccer match.

$$F = umg \qquad \text{(Eq. 7)}$$

Friction force F (in N), friction force constant u, object mass m (in kg) and gravity acceleration g which is, on earth, always about 9.81 m/s^2.

$$F = ma \qquad \text{(Eq. 8)}$$

Acceleration force F (in N), object mass m (in kg), object acceleration a (in m/s^2). Equations 7 and 8 can be solved into equation 9:

$$ug = a \qquad \text{(Eq. 9)}$$

The friction constant u can only be calculated after performing tests. Since the MiS20 would be suited for this task we will determine this constant later on when the MiS20 has been completed[23]. For now we can assume[24] a to be 0,12 m/s^2. This results in u = 1,22*10^{-2}. Equations 10 through 13 illustrate the new velocity, x and y positions of the ball.

$$\begin{aligned} &v(t) = v(0) + at \\ &where\ a \pm 0.12\, m/s^2 \end{aligned} \qquad \text{(Eq. 10)}$$

$$s(t) = s(0) + v(t) \cdot delta\, t \qquad \text{(Eq. 11)}$$

$$x(t) = x(0) + s(t) \cdot \cos(\theta) \qquad \text{(Eq. 12)}$$
$$y(t) = y(0) + s(t) \cdot \sin(\theta) \qquad \text{(Eq. 13)}$$

The ball can also be affected by skidding and a certain rotation speed in multiple axes. Equation 14 displays the moment when the ball stops skidding and starts to roll.

$$delta\ t = \frac{2v}{7ug} \qquad \text{(Eq. 14)}$$

Given is a certain speed v; 1,0 m/s^2. The ball stops skidding and starts rolling after 0,352 seconds. During this time the ball will decelerate a lot faster, as it is resisting the relative ease of rolling across a flat surface. However, this deceleration equation has not been researched for the kinematical representation of the ball as this is a basic model.

3.3.9.2. Robots

The robots in the soccer match can be viewed as simple cubical shaped objects, as was described in paragraph 3.3.8. They have two wheels which enable the robot to maneuver about on the soccer field. Robots, like the ball, have to be simulated having friction; with the floor and with the air. The two wheels on the robot also have a mechanical friction to deal with; when the wheels are ordered to a stop, using new wheelspeeds sent to the robot, the robot will not stand still in an instant. It will gradually come to a halt. This friction can also be determined using only precise position results for which the MiS20 is greatly suited.

Why not use a deceleration for the entire robot? When only one wheel is given the order to stop, the other does not have to be told the same. This is the principle of how the robots maneuver on the soccer field, as illustrated in figure 3.11.

---

[23]. MiS20 is suitable for this task as it can read logged matches from file. The matches contain very precise location and heading information which can be used to calculate the exact deceleration in m/s^2.
[24]. For this assumption, see reference [W13].

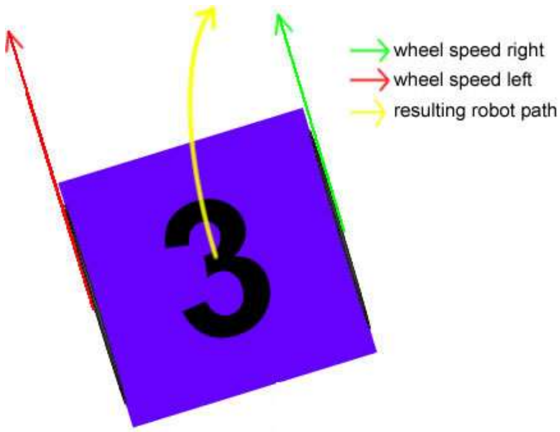


Figure 3.11. Two different robot wheelspeeds result in a new heading

The robot maneuvering will be simulated using equation 15. Both individual wheelspeeds are taken into account combined with the current robot vector results in a new vector for that robot[25]. The distance between the robot wheels is indicated by l, v_{robot} is the robot velocity and θ is the orientation of the robot.

$$\begin{aligned} v_{robot} &= \frac{v_{leftwheel} + v_{rightwheel}}{2} \\ x(t) &= x(0) + \cos(\theta) \cdot v_{robot} \\ y(t) &= y(0) + \sin(\theta) \cdot v_{robot} \\ \theta(t) &= \theta(0) + \frac{v_{rightwheel} - v_{leftwheel}}{l} \end{aligned} \qquad \text{(Eq. 15)}$$

The friction of the wheels with the floor will be simulated using equation 16. An entire robot can accelerate with 1,0 ms^{-2}. Since both wheels are needed to complete this acceleration, the acceleration per wheel is equal to that of the entire robot. The wheel deceleration is 3,0 ms^{2} for both of the wheels.[26]

$$v(t) = v(0) \pm at \qquad \text{(Eq. 16)}$$

Other aspects which are to be reviewed when constructing a kinematical model for a robot such as used in the Mi20 team are: drifting and skidding. As with the ball, we have not researched drifting and skidding for our kinematic representation of the robots, since this is a basic model.

[25]. Vectors are mathematical vectors containing x and y locations, a heading and a timestamp.
[26]. From the Mi20 robot specifications.

3.4. Control

The data model, partially described in paragraph 3.3, will stand at the base of the MiS20. It contains all data which needs to be managed by the Mission Impossible Simulator. The way this data is managed will be described in this chapter. User interactions can be derived from the requirements which where described in chapter 2, using UML use cases. Figure 3.10 displays all interactions with the MiS20 the user can undertake.

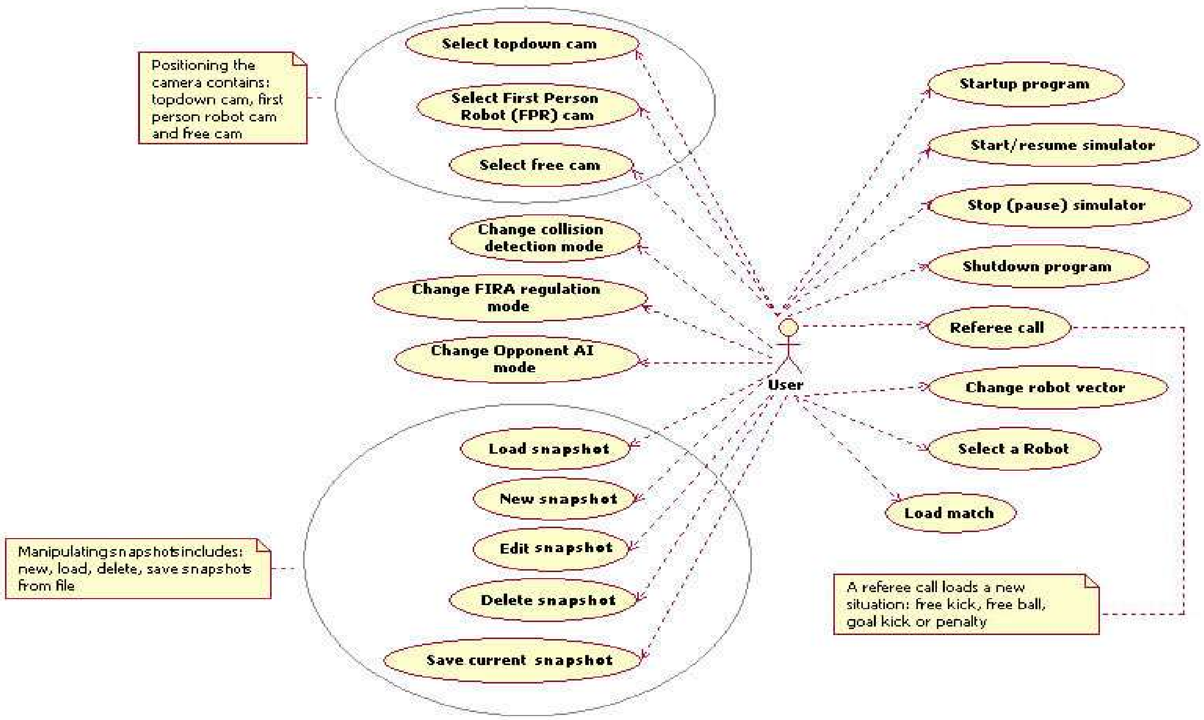


Figure 3.12. User use cases

Each oval in figure 3.12 indicates an interaction with the simulator which a user can perform. We also created two groups of interactions (encircled in gray) because they are very similar to each other.

Figure 3.12 displays all user interactions which are possible with the MiS20. These also include interactions which may not be implemented during this project. The reason why those interactions (“select first person robot (FPR) cam” for example) are included in figure 3.12 is that, according to the requirement stated in paragraph 2.1.5, the simulator must be designed in such a way that extensions are taken into account when designing.

- Selecting topdown camera mode:
  The user selects the top down camera vantage point. The entire field is shown which results in almost the same view which would be generated using the camera system.
- Select First Person Robot (FPR) camera mode:
  The user selects this camera mode after which an object (robot or ball) can be selected in the field view. The camera is then set behind the selected object which results in a pursuit camera.
- Select free camera mode:
  The user selects this mode after which he (or she) can rotate, translate and zoom the camera through the field view until another camera mode is selected.
- Change collision detection mode:
  When the user changes this mode via the menu the collision detection and handling functions will either be or not be used according to the new setting when new vectors for the objects are calculated. All objects can pass through each other and through the walls.

- Change FIRA regulation mode:
  When this mode is changed the FIRA regulations will be or will not be applied according to the new setting. This will only be useful when an automated referee is created since a manual referee applies the FIRA regulations himself.
- Change AI mode:
  It is possible to change the AI settings of both teams. For example a human team using joysticks should be able to play against the AI team. To change this AI setting, the user will have to input a new host address and port numbers. This host address and these port numbers represent the location where the control system for this team is running.
- Load a snapshot:
  The user has the ability to load a snapshot from file. Such a snapshot contains all robot and ball positions and will result in a new match situation. The loading of such a file results in the repositioning of all objects in the field.
- New snapshot:
  When a user wants to create a new snapshot (for instance different starting positions for the robots) this option is selected. The user can reposition all robots and the ball after the match has been paused. It is then also possible to save the snapshot to file.
- Edit a snapshot:
  A snapshot is loaded after which the user can reposition the objects in the field. The snapshot is saved in the same of in a different file.
- Delete a snapshot:
  A snapshot is selected by the user. The simulator then deletes this snapshot.
- Save the current snapshot:
  The simulator is halted when the user selects this option via the menu. The user can then save the snapshot to file which is selected or created by the user.
- Startup program:
  The user starts the Mission Impossible Simulator program. However, the simulator will not begin to simulate.
- Starting or resuming the simulation:
  When the user wants to start the simulation, this option is selected. If a situation is loaded already this situation is resumed. If there is no situation loaded the user must select that situation first.
- Stopping or pausing the simulation:
  The user stops the simulator to make some adjustments such as changing an object's vector or loading a different situation.
- Shutting down the program:
  This exits the program after asking the user if the current situation should be saved first. Log files are written of the played match.
- Manual referee calls:
  The user selects an option such as free ball, free kick etc. by using the referee buttons. A situation is loaded according to the option selected by the user. The options a user referee chooses are determined by applying the FIRA rules.
- Select an object:
  The user selects an object in the field. It depends on the "mode" the simulator is in, for instance an object can only be moved (its vector changed) when the simulator is paused.
- Changing an object's vector (position, heading and speed):
  The selected object's position, heading and speed are changed using the mouse in the field.
- Load match:
  When the Mi20 team has played a match this match will be logged when finished played. Mi20 will need to review such a match using the simulator. The match is loaded from file after which it is in the simulator. Actions such as a referee call will be displayed in the messaging part of the simulator. It is still possible to pause the simulator but no changes can be made to the match (no objects can be manipulated).

3.5. View

This paragraph will describe the design we created for the MiS20 Graphical User Interface (GUI). Multiple aspects were taken into account; required user interactions, shortcomings and good features of the FIRA simulator and various OVID[27] aspects. OVID was not used to its full extent since the GUI provided by the FIRA simulator is almost satisfactory and can be reused to some extent. Figure 3.11 displays the completed MiS20 GUI design.

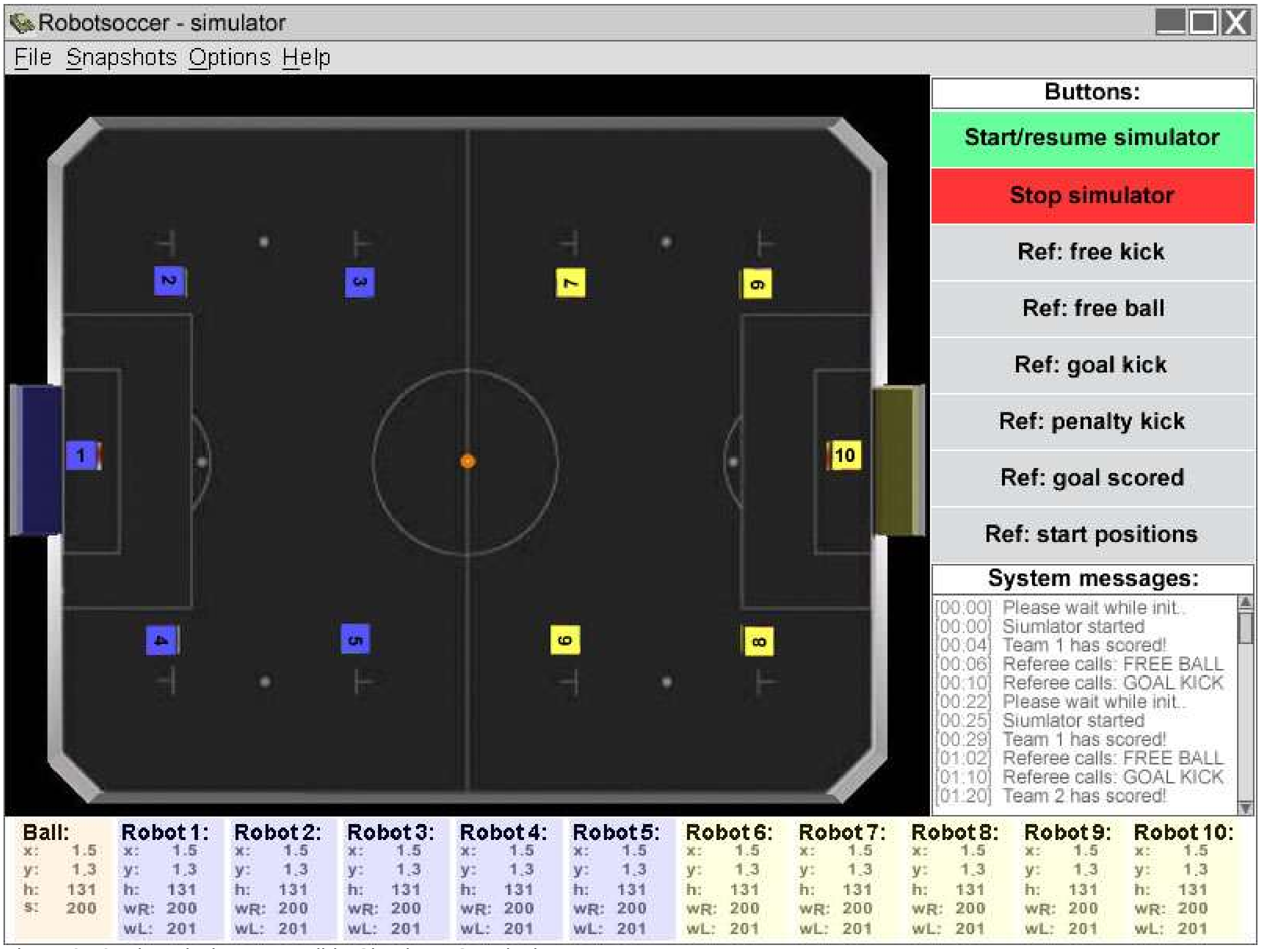


Figure 3.13. The Mission Impossible Simulator GUI design

The most important differences between the MiS20 GUI design and the FIRA simulator GUI are that the MiS20 GUI design incorporates a manual referee application and object location information. Both of these have been created using the user interaction diagram as seen in figure 3.12.

Various Human Computer Interaction (HCI) aspects have been used. The use of colors and contrast, and positioning of GUI components are some examples. The complete analysis of the MiS20 GUI can be found in our design document[28].

[27]. OVID; Objects, View and Interaction Design, see reference [B10] and glossary for more information
[28]. See reference [B3].

3.5.1. Panels

The GUI design shown in figure 3.13 consists of five different panels as shown in figure 3.14. Besides the panels described in figure 3.14, a menubar has been created with which the user can set numerous settings such as turning collision detection on and off, setting new AI settings for both soccer teams, managing snapshot files etcetera. For a complete list of menu items see our design document[29].

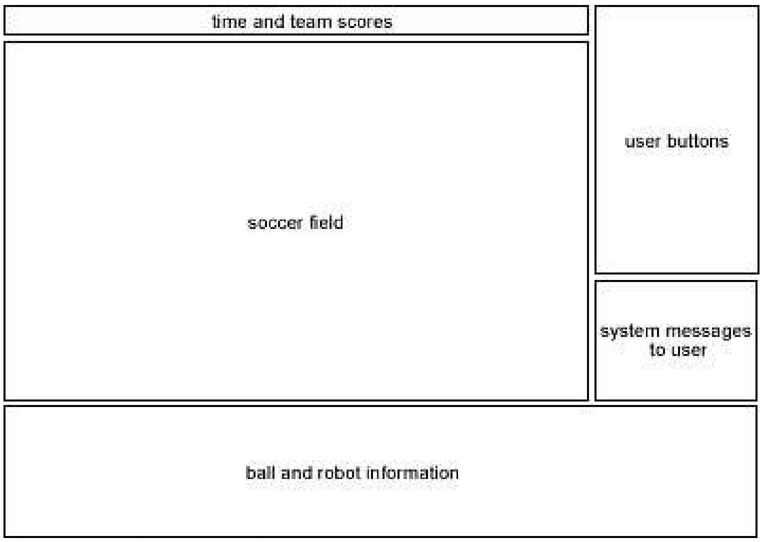


Figure 3.14. The GUI panels

3.5.1.1. Time and scores

The time and team scores are displayed in the panel with the same name. The time is listed in minutes and seconds whereas the number of goals for both teams indicates the score.

3.5.1.2. Soccer field

The soccer field panel displays a 3D representation of the soccer field in which the robots and the ball maneuver. They are, as can be seen in figure 3.13, displayed in an unambigious manner to the user. Colors of the robots are equal to those of the team they are part of. The ball, not being part of a team, will be colored orange. Paragraph 4.3.1.2 describes which technique we will use to display the soccer field in 3 dimensions.

3.5.1.3. Buttons

The button panel enables a user to referee a match manually. A user referee can, using the FIRA regulations, determine a set of five situations[30] to assign to one of the two teams. He (or she) assigns a free ball situation for example after which this snapshot is loaded. All objects (the 10 robots and the ball) are then positioned according to the positions and heading properties found in the snapshot file.

[29]. For the MiS20 design document, see reference [B3].
[30]. A match situation is similar to a snapshot but is called “situation” in the FIRA regulations.

3.5.1.4. Object data

The bottom panel will display the exact robot and ball vector[31] information and the object speed to the user. This object speed consists of two wheelspeeds (one for each wheel) in case of the robots and consists of one speed for the ball. The team colors of the robots are set as a background for each robot in this panel. That way, a user can easily distinguish the robots. The table below displays the meanings of the mnemonics.

Mnemonic	Stands for	Is listed in
x	X axis location of this object	meters
y	Y axis location of this object	meters
h	Heading or orientation of this object	0 through 2 pi
s	Ball speed	m/s
wL	wheelspeed of the left robot wheel	m/s
wR	wheelspeed of the right robot wheel	m/s

3.5.1.5. Messages

The messages generated by the MiS20 are displayed in the similary named panel on the right. An example of such a message is a notification of the user that a team has to be chosen after a referee button is pressed.

3.6. Communication interface

This paragraph will describe the way the communication interface with the Mi20 control systems has been designed. First we will describe what this interface is exactly. Second, what methods can be used to accomplish such an interface. And third, the actual design of this MiS20 program component.

3.6.1. Mi20

The Mi20 system has been implemented entirely in C. It is constructed to be a distributed system which can be run on various machines without having to adjust much in the source code. For this reason, an elaborate set of socket connections has been created which enable the various components of the Mi20 system to communicate with each other[32]. The sockets make use of mutexes to inform the receiver that new data has been sent. The second unusual point about the sockets is that the server sends information to a port on the client's host, and the client listens on its own port. So the Mi20 socket connections "behave" differently from normal client-server sockets.

In chapter one, figure 1.1 illustrated which part of the Mi20 distributed system a simulator will replace. Figure 3.6 displays the interface our Mission Impossible Simulator will have to comply to in order to communicate succesfully with the Mi20 control systems.

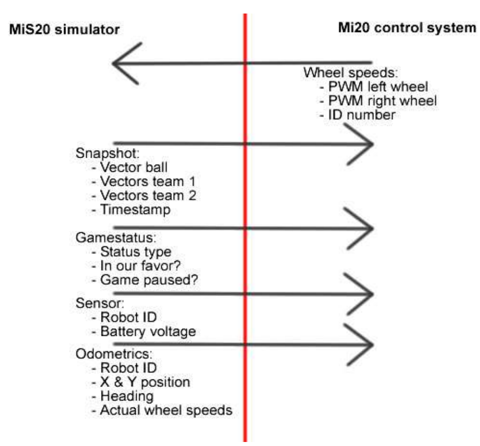


Figure 3.15. The Mi20 communication interface[33]

[31]. A mathematical vector contains x and y positions, a heading and a timestamp.
[32]. Our design document includes a detailed description of this Mi20 component communication.
[33]. A more exact communication interface diagram can be found in the design document, reference [B3].

3.6.2. Sending and receiving

What data actually needs to be sent and received? As described in figure 1.1, wheelspeeds are to be received from Mi20 system three whilst snapshots are sent to system two. However, there is other information which also requires to be sent: the game status (penalty kick for example), robot sensor information (battery indication) and robot and ball odometrics (path which has been pursued). Figure 3.6 illustrates these information packages which are to be sent.

3.6.3. Java Native Interface

Since the interface with the Mi20 systems is programmed in C the interface of the MiS20 communication component must also be in C. However, the requirements in chapter 2 state that the new simulator needs to be build using Java. Therefore a way has to be found to enable Java to communicate with that Mi20 interface in C.

JNI[34] allows Java to communicate with other program languages such as C or C++. JNI uses the JVM[35] in order to communicate with other programming languages. In the MiS20 JNI will be used as well, to interact with the C++ socket communication classes. There are a few other possibilities to communicate with the C interface, the choice of using JNI has been described below:

The possibilities enabling Java to communicate with C++ (and vice versa) are:
- Hexadecimal editing of received (C++) data and edit (Java) data which has to be sent;
- Corba: Java Corba and C++ Corba can communicate with each other;
- Java Native Interface: enables Java to communicate with a library of another language and vice versa.

Pro's and cons of hexadecimal editting:
+ Fast;
+ It might be more platform independent.
- Hexadecimal editing is relatively error-prone compared with native C++ sockets;
- Will data be received and sent as little or big endian[36]? This results in having to know if the processor handles data as big or little endian;
- Hexadecimal editing will result in a great effort to program as well as difficulties to adapt, should the Mi20 communication interface change;
- The communication part has to be written entirely. This means that the threads which receive and send data must be implemented in a way that is fully compatible with the current C++ socket communication.

Pro's and cons of Java Native Interface:
+ The C++ communication can be used, the communication should not be error-prone;
+ Rather fast;
+ Adapting is not very difficult;
+ Can be implemented for more programming languages;
+ Not Error-prone whilst converting data from C++ objects to Java objects and vice versa;
- Debugging can be very difficult, because the error messages contain very little to no useful information;
- The library and all attributes in it are static. This lacks real OO programming[37] in the library.

Corba is not an option because the existing system will not be changed for Corba usage, but it is a very good mechanism to communicate between Java and C++. Also, hexadecimal editing is difficult to program and is more error-prone than JNI.

In conclusion, JNI is the best option to enable communication between the existing Mi20 system (programmed in C) and the MiS20 (which will be programmed in Java).

[34]. JNI, or Java Native Interface see reference [B12].
[35]. JVM, the Java Virtual Machine on which Java runs, see reference [W4] for more information.
[36]. See glossary for more information.
[37]. Object Oriented Programming.

The choice to use JNI, results in having to model the classes, which can be sent/received, in Java. The existing C++ classes/structures are:

- *Tsensor:* a sensor object which is situated on a robot and which uses a set battery voltage;
- *Tgame_status:* describes the status of the game, which robot is in control of the ball etc.;
- *Tsnap_shot:* contains all objects (ball and robots), team numbers, a boolean which indicates if the camera recognition has detected the ball, a time stamp and a number;
- *Tsnap_shot_object:* indicates the position, orientation and color of an object such as the ball and a robot;
- *Todometrics:* contains robot wheelspeeds, location positions and orientation (vectors) and a robot id;
- *Twheel:* structure sent to a robot to actually control it: speed left, speed right, time stamp and a number.

In order to design the use of JNI in the Mi20 simulator it is necessary to study how JNI works. In Java, a native method interface can be written. These methods will be implemented in a native language, such as C++. When a Java object calls such a native method, the JVM[38] will load the native method in the native languages, and apply the parameters on it. When the JVM calls the native method from the library, two extra parameters will be given. The first parameter is an environment pointer, which can be used to call Java objects, classes, methods etc in the native languages. The second parameter is the Java object which has called the native method.

3.7. Decisions summarized

We will use two levels of collision detection to detect collisions between two (or more) objects and between an object and a wall. The first will use AABB collision detection to determine quickly but rather imprecisely if a collision might be possible. The second level will then use OBB collision detection to calculate the exact collision between two objects (if there is one!).

The collision handler handles ball versus robot, and ball versus wall collisions rather well, in order to simulate a realistic match. The robot versus robot and robot versus wall collisions will not be simulated very realisticly, because of the complexity of this. The equations described in 3.3.8.2 will be used.

The kinematical model which will represent the robots and the ball uses object to floor friction to decelerate an object. For this, a constant deceleration is assumed to be 0,1 m/s^2.

We have used the MVC design principle to design our simulator program. It contains the three basic components; model, view and control. However, it also contains an additional communication interface component with the existing Mi20 programming.

XML has been used to store simulator data to files. Two file layouts are used, snapshot and match data which are parsed by the Parlevink XML parser, available at the UT.

Vector information will be recalculated every 33 milliseconds. The GUI is then notified if changes have occured. The vectors are only recalculated when the simulator is running. When stopped, the user can reposition and re-orient objects. This is also stored in the object vector list.

Java Native Interface is being used in order to communicate with the existing Mi20 programming. This is done entirely in the interface component of the MiS20 program. JNI will send snapshots to the Mi20 system and receive wheelspeeds from that system.

Java3D is used to represent the soccer field in 3D. It creates a scene graph which consists of two different branches; objects and view. The 3D world design is based on the FIRA simulator GUI which was reused in our GUI design.

[38]. Java Virtual Machine, see reference [B14]

4. Implementation

This chapter describes the implementation phase of the Mi20 simulator project. Since the design divided the simulator into four distinct components this chapter also describes those four components and the way they interact. Figure 4.1 shows the MVC model which has been used in the design containing the four different MiS20 components. The components represented in this figure are described in this chapter, much in the same way as in the previous chapter. We will first state the design changes we made, followed by the model, view, control and communication interface implementation descriptions. The chapter concludes with a performance issues paragraph in which performance problems and their solutions are described. The Java classes in this chapter are written in italic. The default Java classes' javadoc documentation can be found on the Java 1.4.1. API javadoc page[1]. The MiS20 Java classes javadoc documentation can be found on the MiS20 homepage[2].

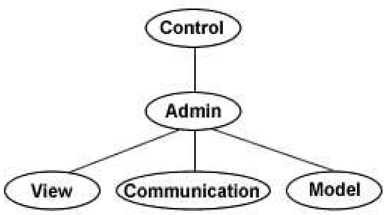


Figure 4.1. Applied MVC model

4.1. Design changes

This paragraph describes what alterations have been made to the simulator design as seen in the previous chapter. The design divides the MiS20 program into four separate components[3]; model, view, control and communication. The exact implementation of these components is described in the following paragraphs; 4.2 through 4.6. Suffice to say, we made no very extensive changes to our design.

4.1.1. The referee

In a match, the referee calls situations from the FIRA regulations, such as free kick, penalty kick and so on. In the MiS20 design the referee object was positioned in the model component where it could manipulate match data. However, since a referee undertakes actions a better position for this object would be in the control component. We also created a *Referee* interface which all new referee objects in the MiS20 must implement.

4.1.2. Settings

In our design we had a number of classes which contained static data. For example, the *SimField* class which contains all data concerning the soccer field. Since that data is not likely to change dynamically we removed all get and set functions which were designed and we made all settings concerning the field *public static final* variables. As described in paragraph 4.6, this also enhances performance for the MiS20 program. An extra class has been created which contains all static information for the Mission Impossible Simulator. This *SimSettings* class also does not need to be instantiated.

4.1.3. Popups

We did not design the use of popup windows in the simulator. These are needed when asking the user to decide which team has to benefit from a certain referee call for example. Also, popups are needed to adjust settings such as the host and port settings in the MiS20 program communication component. We created a class, the *GuiPopupGenerator* class, which has various methods to create and display popups to the user. The actual implementation of this class can be found in paragraph 4.3.

[1]. See reference [W7] for the Java 1.4.1. API javadoc page.
[2]. For the MiS20 homepage see reference [W12].
[3]. The MiS20 design can be found in reference [B1].

4.1.4. Messaging

The message panel, as seen in the design document, contains a list of messages which are displayed to the user. However, to record the messages of a specific match the *SimMatch* class will also have to record the messages displayed to the user in that specific match. Therefore, we added a list of messages to the *SimMatch* class. When a new message is added to that list, the GUI component which displays those messages is informed. See paragraph 4.3.1.4 for a more detailed explanation.

4.2. Model

The model component stands at the heart of the simulator. It contains, coordinates and administrates all data concerning the simulator; matches, object vectors and so on. The *SimAdministrator* class manages match data via its match object. This object contains all data associated with a match (teams, ball etcetera). The designed and implemented UML class diagram of this data model is stated in appendix C.1.

4.2.1. Files

As seen in the analysis and design chapter (chapter 3), XML is used to store and recover information regarding the Mi20 simulator; snapshots and match logs. The XML parser included from the *parlevink.xml* package was used to implement this[4].

The Mi20 simulator administrator (the *SimAdministrator* class[5]) has a link to an object factory[6]. When reading a file from disk, this factory calls upon an implementation of the *parlevink.xml.XMLTokenizer* class. This parser reads the requested snapshot or match from file and returns the required object. When saving a match or snapshot to disk, a *PrintWriter* from the default *java.io* package is used. This object writes a *String* to a given *File* (also from the *java.io* package).

In a snapshot XML file each object has a vector which indicates its position and its heading. The code sample below displays this snapshot vector for an object. The entire snapshot file layout is described in our implementation document[7].

```
        <object id="1" x="0.06500015" y="0.9" h="0.0" />
```

4.2.2. Propertychange events

Chapter 3 describes that object vectors only need to be updated when they have been changed. Whenever a vector has been changed, the GUI is notified using Java property changes. An event is fired by the object (a *SimObject* instance; *SimRobot* or *SimBall*) from the model when its vector has changed. This event is used by the view components listening to this object. There are two GUI components listening to each individual *SimObject*; the 3D representation of that object and the object vector data panel representing that object. The latter is a part of the object vector panel described in paragraph 3.5.1.4. Pro's for using property change events are:

- Implementation of the MVC model in which Model and View are separated;
- More view objects can listen to one data object;
- When the data object fires a property change, the view objects method *propertyChanged* has been called, which can call the *repaint* method, because it is only a view;
- Also works for Java3D;
- A fired property change contains the old and new data.

We do not use Java Observers instead of property changes since we have a lot more experience with the latter and no major performance differences are present[8].

A problem arises when a match is loaded from file. The objects are replaced by new ones, from the new match object loaded from file. The (GUI) property change listeners of that object would be lost. This problem is solved by moving those listeners from the original object to the new version of that object.

[4]. The parlevink.xml parser is a SAX XML parser which reads and returns a tag at a time.
[5]. Java MVC administrator class, complete description can be found in reference [B8].
[6]. An implementation of the factory design pattern, see reference [B6] for more information.
[7]. See reference [B4] for the MiS20 implementation document.
[8]. See reference [W11] for information on performance from the Java programming manual.

4.2.3. Collisions

This paragraph describes how collision detection and handling is implemented in the MiS20.

4.2.3.1. Detection

Collisions can occur between multiple objects and between objects and one or more walls. These collisions are detected using two levels of collision detection as described in paragraph 3.3.8. The first level of detection uses AABBes for each object. An easy check can be performed to test if another object is colliding with a test object. This has been described in paragraph 3.3.8. If the first collision detection algortihm returns a possible collision, a second, more precise detection, is performed. If this test also results in a collision, the collision is handled as described in paragraph 4.2.3.2.

The first level of detection uses equation 2 as stated in paragraph 3.3.8.1. The following code sample illustrates the implementation of this equation. The *SimSettings* class has a number of static class variables which are calculated only once, on program startup. This also improves the performance of this algorithm.

```
float fDeltaX = Math.abs(oA.getVector().x() - oB.getVector().x());
if(fDeltaX  <  SimSettings.fROBOT_COLLISION_SPHERE_RADIUS +
               SimSettings.fBALL_COLLISION_SPHERE_RADIUS   )
{
       float fDeltaY = Math.abs(oA.getVector().y() - oB.getVector().y());
       if(fDeltaY  <  SimSettings.fROBOT_COLLISION_SPHERE_RADIUS +
                      SimSettings.fBALL_COLLISION_SPHERE_RADIUS)
       {
              /* ... a collision might be possible! Go to level 2 detection ... */
       }
}
```

The second level of collision detection uses lines to detect collisions. These lines can be drawn on a *TestFrame* by adding them to the frame that has been made for testing. The robot consists of four lines, one per side (left, front, right and back). A collision between two robots occurs when one or more lines of the first robot intersect one or more lines of the second robot. To detect collisions between objects within the time interval of 30 ms, a line will be drawn from the robot to a point which is the point at which the robot will be on the next update.

Ball collisions will be detected by checking if the distance from the center of the ball to the wall (which is in fact a line) or robots' line is smaller than the ball's radius. Also for the ball, detecting of collisions between updates will be done by drawing a line to the next position, and checking if the ball collides with an object.

4.2.3.2. Collision handling

Collision handling has been implemented using the lines described in the paragraph above. Even the equations described in previous chapter have been used and thus implemented. The handling handles collisions for robot versus robot, robot versus wall, ball versus robot and wall versus ball. The latter two will be handled rather precisely.

4.2.4. Kinematic models

This paragraph describes the way of simulation of the robots and the ball in MiS20.

4.2.4.1. The soccer ball

The ball will be simulated as described in the previous chapter. The formulas described in the previous chapter have been implemented. A deceleration factor has been added to the *SimBall* with which the ball will decelerate every update.

4.2.4.2. The robots

The robots will be simulated as described in the previous chapter. The *SimRobot* contains a maximum deceleration and acceleration. The robots always accelerate or decelerate at max to its target speed. The acceleration and deceleration variables have been retrieved from real world data of matches played by the Mi20 team. The acceleration factor is about 1,0 m/s^2 and the deceleration factor is about 3,0 m/s^2, which includes friction with air and floor. Other formulas which have been used have been described in the previous chapter.

4.3. View

The view consists of several Java graphical packages, Java Swing, Java AWT and Java3D. The resulting GUI of the Mission Impossible Simulator includes all designed GUI components as described in the design and analysis chapter (chapter 3). Figure 4.2 displays a screenshot of the MiS20 in action.

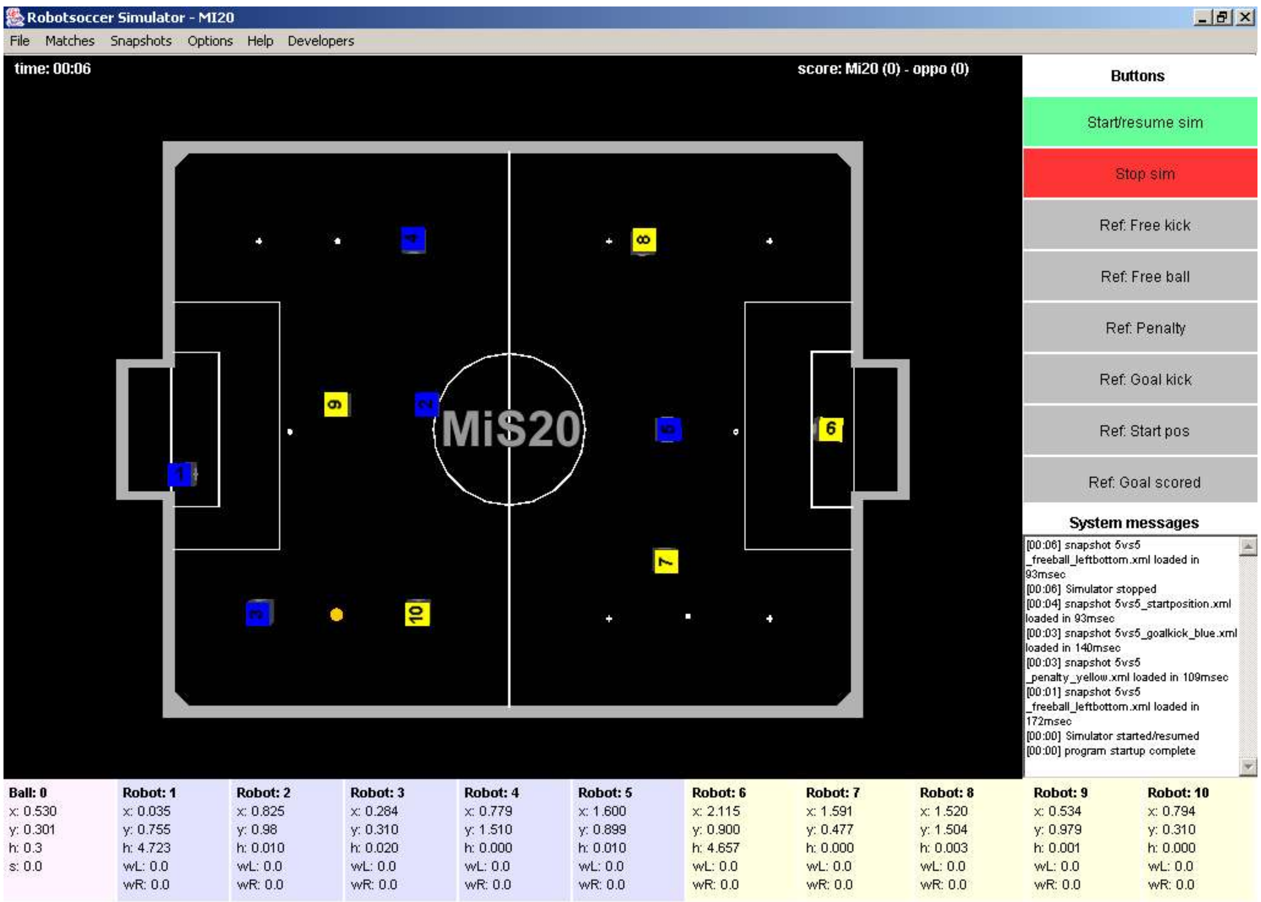


Figure 4.2. A MiS20 screenshot

4.3.1. GUI components

Figure 4.2 displays a screenshot of MiS20 completed. It consists of various panels, each displaying different information to the user. Each of the panels displays another set of information to the user as we already described in paragraph 3.5.1.

4.3.1.1. Menu

The dropdown menu in the menubar implements the class *JPopupMenu*[9]. Since such a menu can result in having to program a great deal of the same source code the menu creating process has been eased by implementing various functions which reuse source code.

[9]. Is a part of the *java.swing package*, see reference [W7].

A *makeMenu(..)* function has been created which creates a *JMenu*[9]. This function creates a tree structered menu. It has a parent menu item (which enables recursive use of the *makeMenu(..)* function) and has a number of menu items located in an array. These items can be a *JMenu* object in itself created with the *makeMenu(..)* function. Also, a target has been added which is an *ActionListener* implementation[10]. The created functions (and classes) result in a great flexibility of the dropdown menu.

4.3.1.2. Field

The 3D representation will be made using Java3D. There is another alternative to using Java3D; OpenGL for Java. OpenGL for Java has however, a few major disadvantages. The most important ones being it not being standardized or widely available, OpenGL exposes inner details of the rendering process which would significantly and unnecessarily complicates the MiS20 program. Java3D is standardized for use with Java and it is easily integrated into our GUI design.

Java3D constructs a scene graph of a 3D world (or scene). This scene graph consists of one (or more) object branch group(s), containing all objects in the scene, and a view branch group, containing all view related components. A simple representation of the Scene Graph used in the MiS20 is displayed in figure 4.3. Because of the relative simplicity of the 3D world used in this simulator the scene graph will be not very complex either.

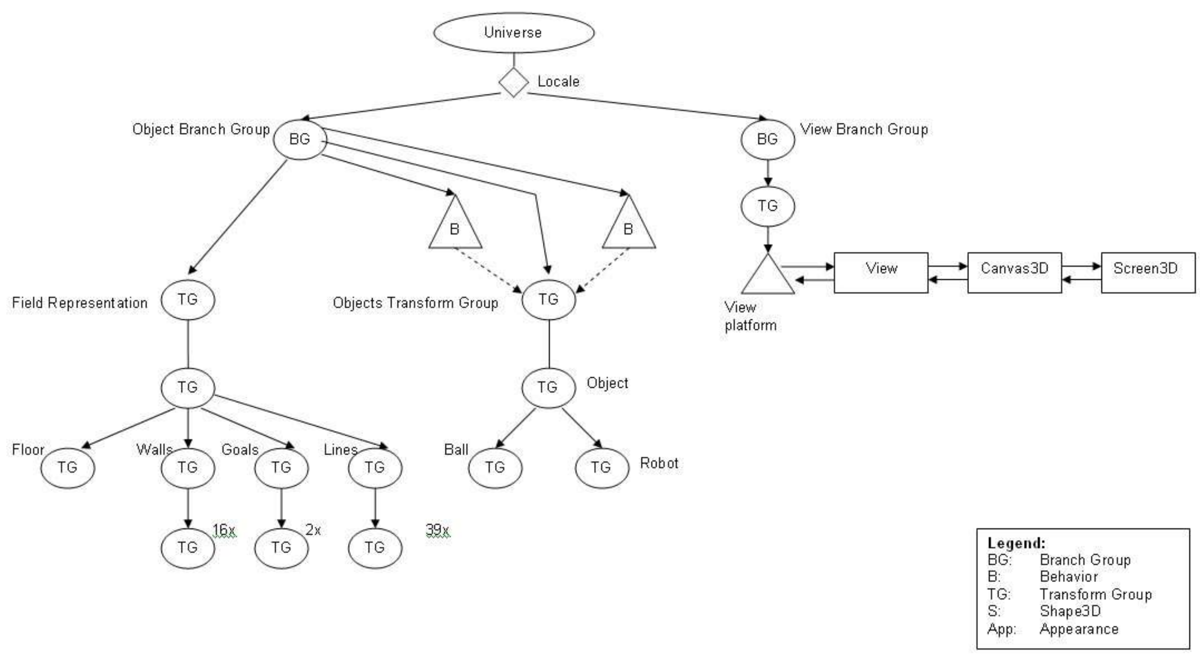


Figure 4.3. Java3D Scene Graph used in the MiS20[11]

The two main branch groups in figure 4.3 contain the objects and view attributes. The view attributes used in the Mission Impossible Simulator are default to Java3D. The object branch group contains all objects in the 3D scene. This branch group can be divided into two separate groups; the static field and the dynamic robots and ball. The latter are dynamic in such a way that they will be translated and rotated by the simulator (and user) at runtime.

4.3.1.3. Buttons

The button panel contains a number of *JButton* implementations. These buttons all have an *ActionListener* which handles button presses by the user. A button has a white border and title which make up it's appearance. A *JButton* generates *ActionEvent*s by default so we only needed to connect the *ActionListener* from the MiS20 control component.

[10]. See chapter 4.3 for information on how *ActionEvent*s are used in MiS20.
[11]. Simplified version of the scene graph, see design document (reference [B3]) for more details.

4.3.1.4. Messages
The messages panel displays system messages to the user. Since a great number of such messages can be generated by MiS20, the user needs the ability to scroll back in those messages. A *TextArea* has been used to add a scroll bar for the user to scroll back. Also, a timestamp is added to each message prior to sending it to this panel. This timestamp indicates the current playtime of the match which starts at 0.

4.3.1.5. Object data
This panel displays all vector information on the robots and the ball. The object data panel consists of 11 subpanels which each display a single object in the soccer field. Each of these subpanels is a property change listener as described in chapter 4.2.2 and updates its data on receiving a *PropertyChangeEvent*.

4.3.1.6. Time and score
This panel contains the playtime of the match and the goals per team. The time is displayed in minutes and seconds.

4.3.2. Heavyweight components
The Java3D package used is a non-standard package provided by Sun, the creators of Java. Combining the use of default Java packages and the Java3D package leads to some difficulties since Java3D uses mainly heavyweight components whilst Java AWT and Java Swing uses lightweight components[12].

One of the places in the MiS20 where this problem occurs is in the menu, which has to be drawn on top of the (Java3D) heavyweight 3D soccer field panel. The problem was solved simply by changing the lightweight property of the *JPopupMenu* to heavyweight. This results in the drop down menus from the menu bar being drawn on top of the 3D field representation.

Another problem occurs regarding heavy- versus lightweight panels when the MiS20 window is resized (to full screen for example). A specific size for each of the panels has to be set. For this reason, all panels in the GUI override the basic *setSize(int, int)* method of the *JPanel* class.

4.4. Control
This simulator component handles all user interactions with the program. It catches user actions such as mouse clicks, keys pressed etc. and informs the simulator that the user has taken some action. For example, when the user presses on the “start simulator” button in the GUI the control component informs the model component that the user wants to start the simulation. After a few checks, the model component enables the communication with the Mi20 control system which sends the robot wheelspeeds.

4.4.1. Action events
The user interactions are handeled using *ActionEvents*[13]. These are fired by various view components such as the referee buttons, described in paragraph 4.3.1.3. When such an event is fired, the corresponding action listener catches this event and handles it. When the referee button “goal kick” is pressed for example, the action listener calls the “goal kick” function of the referee object.

4.4.2. Java3D picking
Not all user interactions are included in this control component, contradicting the MVC model. Java3D requires picking behaviors to be implemented in its scene graph.

To move and rotate the Java3D objects on screen, 2 different behaviors have been used. These two behaviors are the *PickRotateBehavior* and the *PickTranslateBehavior*. If pick reporting of a Java3D object has been enabled, it can be translated and rotated.

[12]. Java heavyweight components are displayed on top of lightweight components, see reference [W6].
[13]. The application of action events in a Java program are described extensively in reference [B11].

The behavior reacts on mouse events, and calls the Java3D object method *setTransform(Transform3D)* to rotate or translate the object. The drawback of the *PickRotateBehavior* is that it rotates the object in all directions, while the robots and ball may only rotate along their y-axis. The drawback of the *PickTranslateBehavior* is that it will move objects in an x- and y-direction, while the robots and ball may only move in an x- and z-direction. For these reasons, the *setTransform* has been overwritten. This overwritten method converts the y-movement into a z-movement, and removes rotations around the x-axis and z-axis.

$$\begin{bmatrix} \cos(\theta) & 0 & \sin(\theta) & x \\ 0 & 1 & 0 & y \\ -\sin(\theta) & 0 & \cos(\theta) & z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \text{(Eq. 17)}$$

The code below illustrates how the information from the matrix will be used in order to create a new *SimVector*. The Transform3D contains the matrix with new positions, which are the old positions with the delta position or heading added. De y rotation will be retrieved from the matrix stated in equation 17.

```
public SimVector getNewSimVector(Transform3D oTransform3D)
{
	Transform3D oldTransform3D = new Transform3D();
	SimObject oSimObject = getSimObject();

	if(oSimObject !=null)
	{
		float fHalfSize = SimSettings.fHALF_CUBE_SIZE;
		if(oSimObject instanceof SimBall)
		{
			fHalfSize = SimSettings.fBALL_RADIUS;
		}
		SimVector oSimVector = oSimObject.getVector();
		float[] matrix = new float[16];
		oTransform3D.get(matrix);

		float newHeading = ((float)Math.asin(-matrix[8]);
			if(newHeading<0)
				newHeading+=(2*SimSettings.fPI);

		// z movement is the y-movement the object will do
		// which is the new y position – old y position
		float fDeltaZ = matrix[7]-fHalfSize;
		SimVector oNewSimVector = (SimVector)oSimVector.clone();
		oNewSimVector.setHeading(newHeading);
		oNewSimVector.setX(oSimVector.x()+fDeltaX);
		oNewSimVector.setY(oSimVector.y()+fDeltaZ);
		return oNewSimVector;
	}
	return null;
}
```

4.5. Communication interface

As described in the previous chapter (analysis & design), JNI has been used to establish communication with the existing Mi20 programming. The current C communication uses mutexes to signal the receiver when new data has been sent. The senders and receivers are both threads. The MiS20 Java communication interface component also consists of send and receive threads. These threads contain a superclass, respectively *CommSendStub* and *CommReceiveStub*, which contain the native functions interface. These native functions are the *sent*, *receive*, *start*, and *destroy* functions.

On starting a send or receive thread, a C++ thread will be constructed, which actually can send or receive data. Passing data from Java to C++ will be done according the native functions, and passing data from C++ to Java will be done according to a retrieved Environment pointer, which is a pointer to the JVM.

Changing from port and host can be done by deleting the old sender and creating a new sender on a specific host and port. The port for receivers to listen to can also be changed. The difficulty with JNI is that a static library has to be used, because of this every sender has to be registrated by the library. Every

native function must check if a sender or receiver has been started yet, or if not, it must wait till the sender or receiver has been started. Further, some problems, for example with thread priority have occured. Receiving and sending objects works correctly, but on deleting a sender or receiver an error occurs because of the receiver or sender thread from the Mi20 communication system.

4.6. Performance

This paragraph will state all performance related improvements we made for MiS20. Profiling is discussed followed by the use of collections of objects. Next we describe the use of *StringBuffer*s followed by using cloned objects.

4.6.1. Profiling

Profiling is a technique which indicates where bottlenecks are in a program. Java has a built-in method to profile a program. By using the *-Xrunhprof* parameter when running a program an elaborate profile of that program is created. These files can be distilled by various programs which offer a graphical view which indicates the problem areas in the profiled program[14]. A Java program is profiled like this:

```
java -Xrunhprof:cpu=samples,depth=6,thread=y  RobotsoccerSimulator
```

The values given along with the -Xrunhprof parameter indicate how to profile the program. The result is a huge file (easily over a few megabytes in size) which contains all method calls down to the user indicated depth level (in this case, six). The table below displays where the bottlenecks in the MiS20 program were. Only the top 10 methods are displayed here. To visualize this a profile analysis tool, PerfAnal[15], was used. It does not generate a graph but offers a structured representation of the program's profile. The percentage column is the percentage of total CPU cycle usage, the calls are the number of calls which were resposible for that percentage:

percentage	**calls**	**function**
67.93%	2726	CommReceiveStub.startReceiverThreadOnSpecificPort
20.41%	819	CommSendStub.startSendThreadOnSpecificPort
5.83%	234	sun.awt.motif.MToolkit.run
0.35%	14	sun.awt.X11Renderer.doFillRect
0.30%	12	javax.media.j3d.Canvas3D.swapBuffers
0.25%	10	javax.media.j3d.Canvas3D.setModelViewMatrix
0.22%	9	javax.media.j3d.Canvas3D.callDisplayList
0.17%	7	javax.media.j3d.Canvas3D.createContext
0.12%	5	javax.media.j3d.RenderingEnvironmentStructure.getInfluencingAppearance
0.12%	5	java.lang.Thread.yield

The main botlleneck functions are to be found in the JNI communication component of the MiS20 program, using almost 90% of the cpu cycles. Both sending and receiving of data for the MiS20 program can be regarded as a bottleneck. The usage of Java3D is not very performance costworthy so we can ignore improving performance there, it uses only 1% of the available cpu cycles.

The sending method used in the communication process converts *SimSnapshot* instances to *CommSnapShotObjects* which are sent to the Mi20 control system. This translation process also requires mirroring of vectors[16] when the Mi20 team is playing from the other half of the soccer field (default is left). This results in overhead which can be reduced to when applying a fast accessable data structure. This is described in paragraph 4.6.2.

[14]. Profiling is described on the Java website, see reference [W1].
[15]. PerfAnal, or Performance Analysis tool can be found on the Java website, reference [W1].
[16]. Mathematical vectors, not to be mistaken by instances of the java.util.Vector class.

4.6.2. Collections

The MiS20 data model contains a lot of information. A match has two teams, each containing five robots. These robots, as well as the ball, which is also contained by the match, have a list of positions called vectors[17]. The parent class for the ball and robot, the *SimObject* class contains this vector collection (of the *SimVector* class). However, there are various approaches on how to actually implement such a collection. One thing to take into account is that the list of vectors will be approximately 18000 units long. There are four good candidates; *LinkedList*s, *ArrayList*s, *Vector*s and arrays of objects[18], all of which can be found in the *java.util* package.

*LinkedList*s are very robust in their usage, they provide in size methods, as well as adding, replacing, iteration functions. However, they do not implement the *RandomAccess* interface. This interface ensures that a list can be searched very fast using random access to the list. A good argument to use *LinkedList*s though, is they have very good performance when managing data in the front to middle sections of a list[19].

A second option is the usage of *ArrayList*s. These lists implement the *RandomAccess* interface which ensures very fast list access. However, ArrayLists are slow compared with *LinkedList*s when managing data in the front of the list since all objects have to be replaced in the list. *LinkedList*s just change their link to the following object in the list in comparison.

Third, *Vectors* are a good alternative. They also implement the *RandomAccess* interface from the java.util package. However, Vectors have overhead whilst it uses synchronized functions. This means it is threadsafe at extra cost. When viewing the design it becomes clear that there is no need to synchronize the objects since only one instance may alter any lists, the *SimAdministrator* instance. Also, when a *Vector* instance has outgrown its original size it automatically allocates twice its current size for future use. In comparison, ArrayLists add only half their size which results in better performance.

Fourth, the use of arrays to store objects is not to be recommended. They have a static length which can only be extended by creating a new array. This results in too much overhead.

Taking all the pro's and cons into account, the best alternative to choose is the use of *ArrayList*s for the vectors.

4.6.3. StringBuffers

A second performance issue is the use of *String* instances. Strings are very often appended using simple “+” operators. These can be relatively costly when used in great numbers.

An example of the use of *String*s in the MiS20 program. Every time a full second has elapsed when a snapshot is created and sent to the Mi20 control system[20], the simulator time (in the GUI) is updated using a property change event. The value sent along is a *String* containing the new time. This *String* is constructed using the *toString()* method of the current *SimTimestamp* class instance. This function calls five “+” operators to create the *String*.

A better and more effective way to accomplish this task is to apply a *StringBuffer*. As its name states, it uses buffering to improve performance aspects.

[17]. Mathematical vectors, not to be mistaken with instances of the java.util.Vector class.
[18]. The Java 1.4.1 API describes all Java API classes in great detail, see reference [W2].
[19]. Perfomance issues for Java programs are described in great detail in reference [W3].
[20]. See reference [B1] for more information on the individual components of the Mi20 system.

4.6.4. Object creation

Every time the vectors are updated using the update thread, a new *SimSnapshot* containing new *SimVector*s for all objects is created. Normally constructors would be used to create a new class instance. However, using a constructor to create a new object is relative costly compared with the copying or cloning of an object.

Arrays can be copied using the *System.arrayCopy()* method. Objects can override the *clone()* method in the *Object* class. There are then two approaches to implement such a *clone()* function; using a shallow or a deep clone. By calling the clone function of the *Object* class, a bitwise copy of the object is created, in other words, a shallow clone. References unique to a specific class instance are to be cloned as well in the MiS20 program. How cloning works is explained in our implementation document[21]. We created a simple clone versus constructor test to measure performance differences between the two. This program can be found in the appendices of our implementation document. The results are:

```
constructor loop took: 131msec
clone loop took: 51msec
```

The results on the previous page prove that cloning is less costly compared with constructor use. The reason that cloning is faster and less costly than using a constructor is that the latter requires calculation of the amount of memory to be allocated. This process is bypassed when cloning as the amount of memory needed is already known. We therefore use cloning as much as possible in the MiS20 program.

Another point to be taken into account can be found in the XML parser we wrote for the MiS20 program. Here, a file is parsed and each XML tag is returned as a *java.util.String*. Since various pieces of match information are to be considered as a float, int or other numeric data we will have to convert these *String*s to their numeric values. For example a number 0 is to converted to int. We can create a new *Integer* class instance of which we call the *intValue()* method. This returns an int value 0 which we wanted. Since constructors are slow compared to static class methods for which no class instance has to be created we are better off using such static methods. The results of a small test program we created:

```
constructor loop took: 128 msec
static function loop took: 41 msec
```

This test, and the cloning test together prove that constructors are to be avoided whenever possible.

4.7. Implementation summarized

The MVC model has been used to implement the MiS20. The program is therefore suitable for reuse and expansion. Using the design described in chapter 3 we implemented the collision detection and handling algorithms in such a way that they can be improved easily.

No major design changes have been made. The referee object was moved from the MiS20 model component to the control component since it undertakes a great deal of (user driven) actions. We created a single class which contains a lot of data which is reused and static for the entire simulator. This will enable future developers to adjust settings easily.

XML files are used to log snapshot and match data of the MiS20 to disk. An available parser at the UT, called parlevink XML has been used and altered to accomplish a working XML file parser.

Property change events are being used to enable communication between the various components of the MiS20. For example, the GUI is updated using property change events fired from the model it represents.

The GUI has been implemented in five separated panels, together they represent the MiS20 data to the user. The soccer field is represented using Java3D to display a three dimensional view of the soccer field.

JNI has been used as an interface between Java and C++. The C++ part contains the communication with the existing (Mi20) system. The problem with using JNI is that a static library has to be created and used.

[21]. For the MiS20 implementation document see reference [B7].

This generates some concurrency problems which had to be solved. Further, on destroying a communication thread, the thread would not always be destroyed, but will sometimes crash. Sending and receiving of data with the Mi20 control system works correctly.

Numerous performance enhancements were made using the results of a profiling session of the MiS20. The type of used object collections has been altered to *ArrayList*s, and objects are created using cloning instead of constructors. Cloning decreases object creation times by almost 67%.

Concluding this chapter, a developers manual has been written for future developers to use in reusing of and expanding upon the MiS20. This manual can be found in our implementation document as well as in appendix C.

5. Testing

This chapter describes the test methods used and results generated in our MiS20 project. MiS20 is divided into four separate components which we will use to structure this chapter as well; model, view, control and communication interface. Various test methods have been used to test MiS20; function testing, fault based testing and functionality testing[1]. These test methods are described in our test document[2].

5.1. Model

The model component contains all essential data concerning the MiS20 program; matches, snapshots, object vector lists etc.

5.1.1.Variables

We have tested get and set functions for correct returning and setting of variables. We used function testing to check if these functions performed correctly. Some variables fire property changes whenever its value has been altered by another object. We tested these property change events by adding *System.out.println(String)* statements in functions which fire and functions which receive these events. Further, we created a developers menu for the menubar of the GUI which enabled us to test which data was present in the model at times of our choosing.

5.1.2. Object creation

As described in paragraph 4.6.4, we use cloning to increase performance when creating new objects. We have tested these methods using function testing to ensure they return the same result when a constructor would have been used. We used the *equals(Object)* methods of the objects which were cloned to check if the objects were equal to their original object version. Also, we ensured ourselves that such a cloned object does not contain any references to the original object's variables by comparing the memory locations of the variables with their cloned counterparts.

5.1.3. XML parser

We used a modified version of the XML parser available from the UT (parlevink XML) for parsing our XML files. It can parse two types of files; logged matches and snapshots. Function and fault based testing were applied to test the correct functioning of the XML parser. The parser also includes write functions which can write these file types (matches and snapshots) to file using the XML layout as described in our implementation document.

5.1.3.1. Writing

Using function testing we wrote bogus snapshots and matches to file. We checked the resulting file to see if it was in the correct XML layout we designed in our design document. A bug was discovered when trying to log a match lasting longer than 2 minutes. We tried to create a single *String* object containing all information for the match file. However, we did not realize that a *String* has a maximum length determined by the system memory size MiS20 runs on[3]. We therefore updated the writing process to write a stream of data to file; every time we have another set of information to be logged it is written to file.

5.1.3.2. Reading

Using the parlevink XML parser we tested correct snapshot and match files which resulted in no errors. We then tried parsing files containing deliberate errors which resulted in program failure. We added some tests to check for valid data and this bug was solved.

[1]. See glossary for more explanation on these test methods.
[2]. For the MiS20 test document see reference [B8].
[3]. For more information see the Java homepage, reference [W4].

5.1.4. Collisions

This paragraph describes the test results gained by testing the collision detection and collision handling techniques we applied. We used functionality testing to test the various algorithms we created.

5.1.4.1. Detection

In order to test the collision detection, the robots were positioned on places with different known collisions. Testing robot versus wall collision detection was done by checking if the individual robot sides intersect with the wall; both of which are represented by two dimensional lines. Further, robot versus robot collision detections were tested in a similar way; we checked if robot sides intersected each other. These intersection were predetermined so we could simply check if they detected a collision when there should be one and the other way around. Robot versus ball collision detection has been tested by calculating the distance of the ball center perpendicular to each of the robot sides. If the resulting distance is larger than the ball radius a collision has occured. These results were checked to see if they were correct.

Further collision detection was tested by rolling the ball at high speed to the wall, and by rolling the ball to a moving robot. Also robot versus robot collision detection when robots are moving was tested by driving the robots towards each other, or letting robots move to the same place.

5.1.4.2. Handling

Collision handling has been tested by simulating ball versus robot collisions and checking if the collisions were handled realistically. Handling ball versus wall collision has been tested by rolling the ball to the wall and checking if the angle in equals angle out. On robot versus wall collisions, the robot's velocity must be zero, also for robot versus robot collisions the velocities of both robots must be zero.

5.1.5. Kinematic models

This paragraph describes how we tested the simulation of the objects. It describes what results were gained from measuring the ball and wheel decelerations. The kinematic models have been tested by performing tests with the real objects (ball and robots) and comparing those results to the results generated by the MiS20. For example, by rolling the ball and checking how long it take before it has stopped. Because of the friction force which has been obtained from the real world, and the physic equations which have been used, the friction will be simulated correctly.

5.2. View

The MiS20 view component was tested per individual GUI panel. We mainly used functionality testing to determine if the correct actions provided by the user resulted in the correct system actions and vice versa. The only major problem we located was found when resizing the GUI. We had to create a resize method manually since Java3D gave us trouble. This function had some difficulties redrawing panels in the correct position. We therefore added a test to check the width and height of each panel after resizing which guarantees the panels have the correct sizes. For the rest, we only found some small errors in the GUI which are described in our test document[4].

5.3. Control

This MiS20 component handles user interactions and the referee object. The latter is controlled by the user who referees a soccer match via the button panel of the MiS20 GUI.

5.3.1. User interactions

Whenever a user presses a button in the GUI he (or she) triggers an *ActionEvent* which is fired by that button. This event is caught by the control component which takes the appropriate action. This is done by comparing the name of the action event in a number of if statements. This is relatively error-prone and during testing often resulted in our not being able to determine which action event was fired. We therefore listed all action event names in the *SimSettings* class as *public static* variables. The *ActionEvent* now contains a static name which can easily be checked:

```
if(oActionEvent.getName().equals(SimSettings.sA_NAME)) { .. /* do something */ .. }
```

[4]. See reference [B8] for the MiS20 test document.

5.3.2. The referee

The referee object will handle all referee calls which are made. Examples are: free ball, goal kick and penalty kick calls. These referee calls all use a different method of the referee object. We tested these methods using functionality testing to ensure that they would perform as expected. When calling a free ball situation the wrong free ball situations were loaded. When the ball was in the upper left corner, the free ball situation for that upper left quarter should be loaded. However, the lower left situation was loaded. We resolved this bug by updating the checks made to test where the ball is located when calling the free ball situation. When the referee has determined that a goal has been scored by a team the start positions are loaded. However, the goal would not be counted for the opposing team. The check which detected a scored goal for that team was fixed.

5.4. Communication interface

The simulator has to communicate with the existing system using the C communication. JNI has been used to let Java communicate with the C communication. To test the communication with the existing system, test classes have been written. These classes send or receive data using the communication which methods which have been used in the simulator. Also C(++) send and receive classes were used to ensure correct testing of the communication.

5.4.1. Receiving

Test programs which send data will be used to test the receiving threads. These programs send data to a port, and the receiver must represent the same data which has been sent. A testprogram has been written for each object which will be sent to the simulator. Each test program consists of a Java sender and a C sender which both sends the same data.

5.4.2. Sending

Test programs which receive data will be used to test the receiving threads. These programs are able to listen to a port to receive on and must represent the same data as has been sent. A testprogram has been written for each object which can be sent by the simulator. Each test program consists of a Java receiver and a C receiver which can both receive data.

5.5. Tracebility matrix

The test result matrix has been derived from the traceability matrix[5] in the test document[6].

System requirements	***Test succeeded***
2.1.1. Interface between the simulator and Mi20 system	yes
2.1.2. Approximate correct simulation of the robots and ball	yes, rather good
2.1.3. FIRA regulations	yes
2.1.4. Logging of data	yes
2.1.5. Expansion	yes

[5]. A traceability matrix contains the relation between requirements, design and test. It contains the chapter numbers in which documentation has been written.
[6]. For the MiS20 test document, see reference [B8].

User requirements	***Test succeeded***
2.2.1. Object and object data representation	yes
2.2.2. Options	yes
2.2.3. Stopping and resuming the simulator	yes
2.2.4. Match data	yes
2.2.5. Manual referee	yes
2.2.6. Messaging	yes
2.2.7. Manipulating Objects	yes
2.2.8. Logging matches and snapshots	yes

Implementation requirements	***Test succeeded***
2.3.1. Programming language(s)	yes
2.3.2. Error handling	no
2.3.3. Assertions	no

Optional requirements	***Test succeeded***
2.4.1. Multiple camera vantage points	No, has not been implemented
2.4.2. Automated referee	No, has not been implemented

5.6. Testing summary

Various testing methods have been used to thoroughly test the MiS20. Of these, function, functionality and fault based testing are the most important ones.

The kinematic models of the ball and robots have been tested by checking data generated by the MiS20 and comparing that to the data generated using the actual robots and the actual ball.

The communication with the Mi20 control system has been tested by creating small test programs to simulate the communication with that control system.

6. Results

The results chapter will describe the results of our MiS20 project as documents and the simulator itself.

6.1. Documents

During the project several documents have been written. These documents are:

- Start document containg management aspects of the project.
- Requirements document, containing all the requirements given by the Mi20 members.
- Design document which describes the analysis and design of the MiS20.
- Test document which describes the tests and their results.
- Implementation document containing implementation results as design changes.
- User manual describing the use of the MiS20.
- Developers manual describing the way in which the simulator can be expanded.
- Final document this document.

6.2. MiS20

This paragraph describes how well MiS20 complies with the project requirements and project goal. First we will describe to what extend the integration with the existing Mi20 system has been accomplished. This is followed by determining the level of simulation which MiS20 boasts.

6.2.1. Integration

The Mission Impossible Simulator has to be used by the Mi20 team to test and train their (AI) robot controlling techniques. MiS20 has to comply to a set communication interface. This enables the MiS20 to fool the Mi20 control system into believing it is controlling the actual robots. Paragraph 6.1.2 will describe how well we managed to fool that control system.

The communication interface to which MiS20 complies has been implemented using JNI. Using this technique, the Mi20 control system is not able to notice the difference between the simulator (MiS20) and the normally used global vision system combined with the real robots on the soccer field. This can be proven since MiS20 uses the actual (C) implementation of the Mi20 team to send and receive data via the socket connections with the Mi20 control system.

6.2.2. Approximately correct simulation

The MiS20 project goal states that the robots and the ball have to be simulated in an approximately correct way. The level of MiS20 simulation is described in this paragraph. Simulating a robot soccer match can be divided into three components: normal moving, collision detection and collision handling.

6.2.2.1. Kinematic models

The kinematic models which were created for the robot and the ball included aspects concerning movement on the soccer field using orientations and speeds. They also included friction which slows an objects down to a halt eventually. The movements on the soccer field are equal to those when viewing an actual soccer match which the MiS20 simulates. The friction with the floor makes objects stop at the same speeds as they would in a real soccer match.

However, the MiS20 does not handle kinematic aspects such as skidding and drifting of objects on the soccer field. This often occurs in a real match but is rather difficult to simulate.

The value used in the MiS20 for ball deceleration, caused by friction, has been determined at $1,194 * 10^{-1}$ m/s^2. We have used the values from the logged Mi20 matches to determine this value[1].

[1]. The ball had a loss of speed during 6,132 seconds of 0,732 m/s. Dividing the latter by the first results in a deceleration of $1,1939 * 10^{-1}$ m/s^2.

The robot has a set deceleration[2] of 3,0 m/s^2, and a set acceleration for each wheel of 1,0 m/s^2. We have used the MiS20 to test these values as well and they are correct.

The maximum speed of the ball is 3,63 m/s, which can be calculated using equation 5 in paragraph 3.3.8. This maximum speed can only be reached when the ball is traveling at the highest speed possible for it and when a robot can still catch up with it from behind to accelerate it even further. Since a robot has a maximum speed of 2,0 m/s this maximum speed for the ball is 1,99 m/s. Using the stated equation, the ball can reach a speed of 3,63 m/s. Further collision to accelerate the ball are not possible since they would only decrease its speed.

6.2.2.2. Collision detection

Collisions are detected using the two detection techniques described in paragraph 3.3.8. Collisions between objects and objects and between objects and walls are, as described in chapter 5, detected very precisely. A few exceptions remain however; when an object collides with more than one wall at any one time the collision is not handled correctly which results in unwanted events. However, this hardly ever occurs.

6.2.2.3. Collision handling

Collisions between objects and objects and between objects and walls are handled very basically. When two robots collide they do not use a collision model to simulate an elastic or inelastic collision, they just stop. When the ball collides with a robot or with the wall it will reflect off again with a little momentum lost[3] and with the same angle outward as inward.

6.2.3. OS indepent

The MiS20 is not operating system indepent regardless of it being constructed in Java. The reason for this is that the communication component, using JNI, cannot function properly on a windows or linux operating system. The static link library needed for it to function cannot (yet) be compiled on a windows or linux OS.

[2]. This is one of the characteristics of the robots as was determined by the Mi20 team, see reference [W1].
[3]. As can be calculated using equation 5 in chapter 3.

7. Conclusions

7.1 Comparison with the current simulator

When comparing MiS20 with the current FIRA simulator, there are some advantages and disadvantages for MiS20:

- \+ Open source;
- \+ Continues playing;
- \+ More accurate kinematics, dynamics and position representation;
- \+ Java 3D and Java ensure easy acces for future developers;
- \+ Expandable;
- \+ Runs on Solaris;
- \+ No constant replay after scoring;
- \+ Loading/saving situations and replaying and saving matches;
- \+ Robot representation with identifier;
- \+ Run-time configurating of ports (has to be adapted);
- \+ Manual referee;
- \+ Sizes of field, robots and ball can be changed without effecting the simulation;
- \+ Team size can be changed in order to simulate matches for e.g. the small-size league;
- – Realtively low speed;
- – Not running on Windows yet because building a library for JNI went wrong;
- – Collision handling does not meet the approximately correct simulation requested;

7.2 Dynamic and kinematic models

The kinematic models are very realistic according to physics formulas. The friction forces have been calculated using real world data, and are also very realistic. Only the sliding of the ball and the wheels and center fleeing force can be implemented to make it even more realistic.

7.3. Collision detection

Collision detection is a very costly venture for which a great number of algorithms have been created, mainly by the gaming industry. We have used two techniques to determine collisions as fast and as accurately as possible. The first technique of collision detection, AABBs, can hardly be faster. It can be implemented to be more accurate though. However, this would result in a performance drop.

The second technique used to detect collisions, OBBs combined with bounding spheres, is already very accurate. However, it still does not detect collisions as well as it should do. A more accurate technique could be used here, however, that would result in an even greater drop in performance for the MiS20.

7.4. Collision handling

Collision handling is a very difficult problem in any simulation. We have tried to simulate collisions as precisely as possible, but handling multiple collisions on one object at the same time is not always realistic.

7.5. Overall conclusion

According to pro's and cons described in paragraph 7.1, we have delivered a rather accurate simulator, which is more accurate than the current (FIRA) simulator. The Mission Impossible Simulator can be adapted easily, to perfect the collision handler, or dynamica on some points. The collision handling can be more accurate on the points described, but it is very hard to make a good collision handler.

Is our project goal, to create a simulator to simulate a match of robot soccer in an approximately correct way, accomplished? We are sure it is. Improvements can still be made to update the level of simulation the MiS20 boasts but it is accurate enough to be able to simulate a match of robotic soccer to a rather accurate extent.

8. Recommendations

This chapter describes the recommendations for people who wish to adapt the MiS20. The most important recommendations have been described.

8.1. Simulation

8.1.1. Ball simulation

The ball can be simulated even more precisely than is done at this moment. Skidding and drifting can be simulated and also the dents in the ball can be simulated. Equations to accomplish this have not been written in this document, so they have to be found in other relevant documentation, on the internet for example.

8.1.2. Robot simulation

The robot can be simulated more precisely by implementing skidding and drifting. Equations to accomplish this have not been written in this document, and so they have to be found in other relevant documents, on the internet for example.

8.2. Collisions

8.2.1. Collision detection

The collision detection can be optimized for detection of collisions between updates. For now these collisions will be detected by one line which is the path till the next update. This line might be changed in the shape of the object.

Further, to optimize the collision handler, a time of collision may be added. The reason for this will be explained in the next paragraph.

8.2.2. Collision handling

The collision handling can be optimized on points described in the following paragraphs.

8.2.2.1. More accurate multiple collision handling

Collisions between multiple objects within a time interval can be handled in a more accurate way. This means the time of collision described in paragraph 8.2.1. will be used.
Handling of collisions will be according to the following steps:

1. when the collisions detection algorithm has detected any collisions, the objects will be updated till the first collision occurs;
2. the first collisions will be handled;
3. when the collisions has been handled, new collisions must be detected during the interval till the next update occurs.
4. if collision(s) have been detected, repeat the steps 1 through 4.

This method will give a very precise simulation of collision in time.

8.2.2.2. Handling robot collisions

Handling robot versus robot and robot versus wall collisions can be improved by simulating the collisions in a rather realistic way. For example when a robot runs into another robot, both robots will drift. Equations to simulate this have not been described in this document.

8.2.2.3. Handling ball collisions

Handling ball versus robot and ball versus wall collisions can be improved by giving the ball a drift or skid force on collision. When doing this, it must be taken in account that the ball also obtains a special drift/skid when colliding into a wheel. Drifting and skidding have effects on the path the ball will roll.

8.3. JNI interface with the C++ communication

The interface between Java and the C++ communication part can be improved to work more concurrently and faster. This means that the library has to be adapted. How this interface has to be adapted needs to be researched.

8.4. Running on other Operating Systems

The MiS20 can be adapted to run on Linux or Windows, because on both C++, Java, Java3D and JNI can be used. The problem which must been fixed is that the we cannot build a JNI library on Windows. To be able to run the simulator on Linux, logically a Linux machine must be present. This was not the case during our project.

8.5. Implementing optional requirements

Optional requirements which have been set are the automated referee, and the ability to change the camera position. The automated referee can be implemented using object data, and must referee according to the FIRA rules. Changing the camera will be not so difficult using the camera class we implemented.

8.6. Sliding bar for replaying matches

A sliding bar could be very handy. This bar represents the time of the match. Using the mouse, the bar slides to a specific timestamp, so rewinding and forwarding to a timestamp has been enabled. This option will give the user the ability to skip moments in which no robots move e.g. or rewind to view a certain match interval again.

8.7. More time

The MiS20 is currently designed to be a realtime simulator since the Mi20 control system does not, as yet, use a learning AI system to train the robot control. However, when this is completed and added to the Mi20 system in the near futute it is very conceivable to use a non realtime simulation to train the Mi20 AI, for example in non working hours. Instead of an update every 33 milliseconds, this can be ten times as much. However, the simulated time would still be 33 milliseconds. This results in getting to spent 297 milliseconds more time on detecting and handling collisions for example which, in turn, results in a much more accurate simulation.

9. Personal reflection

Besides the project goal there are some personal goals which need to be achieved, some of which are:

- Completing a non routine project assignment on an independent level;
- Application of learned theoretical knowledge;
- Using a structured project approach;
- Practicing social interaction with colleagues.

Robotic soccer uses cutting edge techniques such as agent based systems. We have learned a great deal from the methods which are used to apply these techniques. When working on our project we were left to accomplish and study problems we encountered on our own. This may have resulted in some unnecessary loss of time since we could have asked right away. But it also resulted in us learning to adjust and learning to do things indepently.

During the creation of the MiS20 we applied different design methods such as NIAM, OVID and UML all of which we learned at the Saxion Hogeschool Enschede. We also applied technical knowhow regarding implementation techniques such as design patterns and so on. An improvement could be that we could study other design and implementation techniques and make a more informed choice about this.

The MiS20 project was structured in an iterative way. This enabled us to expand on previously constructed work and also ensured we would have a working program in some form at the end of the project. We did not, however, release these different iterations for public use by the Mi20 team since they still used the FIRA simulator. This simulator could only be replaced when our MiS20 was fully completed.

Since we needed to work with the UT students constructing the UT's Mi20 robot soccer team we had a lot of social interaction with colleagues. We also approached UT employees with questions regarding Java3D, collision detection algorithms, document reviewing and so on. Every time we were treated with respect and as equals which motivated us really well.

Further, the project tutors really did a good job. Ir. Meuleman informed us about all aspects of our project we needed to know such as deadlines etc. We also had feedback from Dr. Poel and Ir. Meuleman about this thesis which resulted in a better document.

9.1 Personal reflection of Hans

During this project a wide range of programming aspects have been used, which is very nice. Further programming in different languages and combining them together has been a good lesson in the course of becoming a software engineer. Also, knowledge of simulation aspects has been obtained. All in all, this project was very challenging with aspects of simulation, Java3D programming, delivering a simulator for use in a real-time distributed system.

9.2. Personal reflection of Wim

During the MiS20 I learned a great deal. I learned to create an even better design than I had so far during my college period. Programming aspects regarding Java, Java3D en JNI also intriged me very much. Further, I really enjoyed working at the University of Twente, so much even that I am going to try a sequel study there. One other aspect which did appeal to me greatly was the need to study a great deal of literature before even beginning to apply it in my project.

References

Documents:

[B1] FIRA Middle League MiroSot Game Rules
Federation of International Robot-soccer Association
[B2] Robot soccer – Start document
H. Dollen, W. Fikkert
[B3] Robot soccer – Design document
H. Dollen, W. Fikkert
[B4] Universele Informatiekunde
Prof. dr. ir. G.M. Nijssen, PNA Publishing BV - ISBN: 90-5540-0017
[B5] Design Patterns - Elements of Reusable Object-Oriented Software
E. Gamma, R. Heml, R. Johnson, J. Vlissides - ISBN: 0-203-63361-2
[B6] Java Modeling in Color with UML
P. Coad, E. Lefebvre, J. De Luca
[B7] Robot soccer – Implementation document
H. Dollen, W. Fikkert
[B8] Robot soccer – Test document
H. Dollen, W. Fikkert
[B9] Designing for the User with OVID
D. Robert, D. Berry, S. Isensee, J. Mullaly, D. Roberts - ISBN: 1-57870-101-5
[B10] Core Java Fundementals
Authors Cay S. Horstman, Gary Cornell ISBN: 0-13-081933-6
[B11] Core Java Advanced Features
Authors Cay S. Horstman, Gary Cornell ISBN: 0-13-766964-8
[B12] Lin, Ming C., Gottschalk, Stefan, Collision Detection between Geometric Models: A Survey, Proceedings of IMA Conference on Mathematics of Surfaces, 1998
[B13] Java Virtual Machine
Jon Meyer, Troy Downing ISBN 1-56592-194-1
[B14] Binas
Wolters - Noordhoff ISBN 90-01-89372-4
[B15] Motion planning in a robot soccer system
W. Dierssen

Websites:

[W1] Mi20 homepage, Computer Science, University Twente
http://parlevink.cs.utwente.nl/robotsoccer/
[W2] FIRA | Federation of International Robot-soccer Association – homepage
http://www.fira.net
[W3] FIRA European Chapter – homepage
http://www.ihrt.tuwien.ac.at/FIRAEC/default.htm
[W4] Java homepage at Sun
http://java.sun.com
[W5] Gamasutra advanced collision detection techniques
http://www.gamasutra.com/features/20000330/bobic_03.htm
[W6] Java3D Tutorial
http://java.sun.com/products/java-media/3D/collateral/
[W7] Java™ 2 Platform, Standard Edition, v 1.4.1 API Specification
http://java.sun.com/j2se/1.4.1/docs/api/
[W8] 3D Graphics programming in Java, part 3: OpenGL
http://www.javaworld.com/javaworld/jw-05-1999/jw-05-media.html
[W9] CVS homepage
http://www.cvshome.org/
[W10] Collision detection algorithms
ftp://ftp.cs.unc.edu/pub/users/manocha/PAPERS/COLLISION/wafr.pdf
[W11] Java programming – performance chapter
http://www.algebra.hr/Java%20programing.pdf
[W12] MiS20 homepage, Computer Science, University Twente
http://wwwhome.cs.utwente.nl/~fikkert/
[W13] Physics on the Back of a Cocktail Napkin
http://www.darwin3d.com/gamedev/articles/col0999.pdf

Glossary

AABB	**A**xis **A**ligned **B**ounding **B**ox. A collision detection techniques which creates a bounding box around an object and checks collisions between these boxes. Hence, this is a fast but rather inaccurate method of detecting object collisions. See also; OBB.
AI	**A**rtifical **I**ntelligence, a system which can learn and make intelligent decisions based on the information provided.
Big endian	See little endian.
FIRA	**F**ederation of **I**nternationl **R**obot soccer **A**ssociation. An association which organizes and hosts various robotic soccer events around the globe in order to contribute to a better undestanding of various new techniques as AI, multi agent systems etc.
Heading	The orientation of an object in the MiS20.
Little endian	The adjectives big-endian and little-endian refer to which bytes are most significant in multi-byte data-types and describe the order in which a sequence of bytes is stored in a computer's memory
Mi20	**M**ission **I**mpossible Twente, the University of Twente's robot soccer team in the FIRA MiroSot middle league. See also MiS20.
MiS20	**M**ission **I**mpossible **S**imulator, the simulator which was constructed for use in the Mi20 project. See also Mi20.
NIAM	"**N**atuurlijke taal **I**nformatie **A**nalyse **M**ethode", or Natural language Information Analysis Method. NIAM distilles data structures from a project description. These data structures can then be used to create a database, UML objects etc. See also UML and OVID.
OBB	**O**riented **B**ounding **B**ox. A collision detection technique which creates a bounding box around an object. Such a bounding box is aligned with the local axes system of the object. See also AABB.
Object	An object in the Mi20 simulator is a generalization of a robot and a ball. It contains a list of vectors (see "Vector") among other information.
OVID	**O**bjects, **V**iews, and **I**nteraction **D**esign is a formal methodology for designing the user experience based on the analysis of users' goals and tasks.
Snapshot	A snapshot contains location and heading information of each object (see "Object") at a specific moment during the match. Hence, all objects are included in a snapshot.
UML	UML stands for **U**niversal **M**odeling **L**anguage. It is a modeling technique designed by Grady Booch, Ivar Jacobson, and James Rumbauch of Rational Rose. It is used for OOAD (Object Oriented Analysis and Design). It is supported by a broad base of industry-leading companies which, arguably, merges the best of the various notations into one single notation style. It is rapidly being supported by many tool vendors, but the primary drive comes from Rational Rose.
Vector	A vector is to be regarded as a mathematical vector; it indicates an axis position along the x and y axis and a heading from that position.
Function testing	Tests each individual function as if it were a black box. We will know what goes in and what should come out. If the correct return value is fetched on multiple inputs, the function should be correct.
Fault based testing	Input illegal data and see if the program handles that illegal data correctly (generates the correct error message).
Functionality testing	Testing the system in general for functionality: for example checking if all buttons do what is expected from them.

Appendices

The appendix chapter consists of the following:

Appendix A. Project schedule

This appendix contains the project schedule which was created. Also, we will discuss the problems we have had trying to uphold this schedule.

Planning when activities have been done.

Week	Activity finished
6	Information about the UT's robot soccer team;
	Programming and project specific information;
	Address information;
7	Documentation robot soccer problem(s) in general;
	NIAM;
	Design : Prototype
8	Start document;
	Basic class diagram, using the NIAM analysis;
9	Use cases;
	Sequence diagrams;
	User interface (how will it look?);
	Software design patterns (which software patterns will we use?);
10	UML analysis;
	Analysis of General object behavior;
	Analysis of Object collision behavior;
11	Field visualisation;
	Object visualisation;
	Java native methods for communicating with C code from Java;
12	Implemented Prototype
	Object collision detection;
	Object information display (position, heading, speed(s) etc);
	Basic collision handling (angle in = angle out etc.);
	Testing Prototype
13	Basic object behavior (a set acceleration speed etc.);
14	
15	Advanced collision handling (using the correct kinematic data);
	Advanced object behavior (using the correct data);
	Testing simulator
16	Implementation document;
	Camera positioning;
	Object history display (log display; path of movement);
17	Team score display;
	Match elapsed time display;
18	Robot selection;
	Free camera positioning;
	Robot first person view camera;
19	
20	Test document;
	User driven referee;
	Requirements testing;
21	
22	Simulator javadoc
23	Final document;
	Code reviewing;
	Source code testing of the simulator
24	Summary on project for other students;
	Automated referee;
25	Website;
	Final presentation;
	Progress meetings;
	Unexpected setbacks;

Actual week when activity has been finished.

Week	Activity finished
6	Information about the UT's robot soccer team;
	Address information;
7	Programming and project specific information;
	Documentation robot soccer problem(s) in general;
8	Start document;
	Use cases;
	NIAM;
	Basic class diagram, using the NIAM analysis;
9	User interface (how will it look?);
	Software design patterns (which software patterns will we use?);
	UML analysis;
	Design : Prototype
10	Requirements document
11	Sequence diagrams;
	Implemented Prototype
	Testing Prototype
	Analysis of General object behavior;
12	Field visualisation;
	Object visualisation;
	Basic object behavior (a set acceleration speed etc.);
	Java native methods for communicating with C code from Java;
13	
14	Object information display (position, heading, speed(s) etc);
15	Object collision detection;
	User driven referee;
16	Robot selection;
	Analysis of Object collision behavior;
	Match elapsed time display;
17	Basic collision handling (angle in = angle out etc.);
18	Team score display;
	Advanced object behavior (using the correct data);
19	Testing simulator
20	Implementation document;
	Replaying played matches
21	Summary on project for other students;
22	Code reviewing;
	Advanced collision handling (using the correct kinematic data);
	User manual, describing the usage of the MiS20;
23	Source code testing of the simulator
	Simulator javadoc
	Requirements testing;
	Test document;
	Testing simulator
	Developers manual
24	Final document;
25	Website;
	Final presentation;
	Progress meetings;
	Unexpected setbacks;

Red = has to be optimized.
Green = activity has not been planned, but is necessary.

Unfinished activities:
Object history display (log display; path of movement);
Camera positioning;
Robot first person view camera;
Free camera positioning;
Automated referee;

All unfinished activities are optional requirements. We planned them in order to finish the activities if there had been plenty of time.

As seen in the tables above, some activities have not been finished. These activities have not been implemented. Further the collision handling will be adapted in order to handle collisions rather correctly. The design for the prototype took 2 weeks longer because we first had to make the uml analysis etc. Collision detection and handling were more difficult than we had thought at the start of the project. This resulted in those activities have been finished some weeks later.

Appendix B. User manual

This appendix contains the user manual for the MiS20 program. Basic knowledge to operate a computer is thougth of as basic knowledge.

Warnings

When using the Mission Impossible Simulator (MiS20) take note of the following precautions.

- Maintain a distance from the screen;
- Use a computer screen preferably;
- Do not use the MiS20 when tired or in lack of a good nights' sleep;
- Use the MiS20 in a well lit enviroment;
- When using the MiS20, take 10 to 15 minutes rest for each hour of use.

Contents

Preface

Since 1997 various robot soccer initiatives have set up robotic soccer leagues. These leagues are an international research effort of which the goal is to explore and apply new and promising techniques in the area of robotics. The University of Twente has set up its own AI controlled team (Mi20) in the FIRA MiroSot middle league. This team needs to be trained and tested in a simulator program. The FIRA simulator, normally used for the SimuroSot league does not suffice. Hence, the Mission Impossible Simulator (MiS20) has been born.

The MiS20 enables users and robot soccer developers to research and apply new techniques without having to use the actual robot soccer team. This team is, as well as the opponent team and the ball, simulated in the MiS20. A user can referee a match as stated in the FIRA game rules.

For more information on this and other University of Twente projects see the parlevink computer science website: http://parlevink.cs.utwente.nl.

Program controls

Action	Keyboard control	Mouse control
Start the simulator	CONTROL + A	Click “start/resume sim” button
Stop the simulator	CONTROL + O	Click “stop sim” button
Exit the simulator program	CONTROL + X	
Create a new snapshot	CONTROL + N	
Load a snapshot from file	CONTROL + L	Click one of the referee “ref: X” buttons: - Free kick - Free ball - Penalty - Goal kick - Start pos - Goal scored
Open a snapshot for editting	CONTROL + E	
Delete a snapshot from disk	CONTROL + D	
Save the current snapshot to disk	CONTROL + S	
Loading a match	ALT + M, L	
Resetting a match	ALT + M, R	
Deleting a match	ALT + M, D	
Save a match to file	ALT + M, S	
Set own team (Mi20) control method	ALT + O, M	
Set opponent team control method	ALT + O, O	
Toggle collision detection on/off	ALT + O, S, D	
Toggle FIRA game rules on/off	ALT + O, S, R	
Toggle warning messages on/off	ALT + O, S, W	
Auto continue when loaded from file	ALT + O, S, C	

System requirements

Before running the simulator, please check if your system meets all system requirements as stated below:

- Unix operation system with any desktop environment;
- Java J2EE or J2SE v1.4.1 installed;
- Java3D v1.3.1 installed;
- CPU of 1000 MHz or greater
- 256 MB of RAM or more;
- A screen resolution of 1024*768 or greater is recommended;
- 200 MB of disk space.

Running the simulator

The simulator has been implemented using Java. No executable has been created to start the MiS20 so you will have to run the program using the installed Java version on your machine. See the system requirements for the version number.

To run the MiS20 go to the command prompt. Make sure Java and Java3D are set in the classpath and path of your system. Also, make sure the library path has been set to the simulator directory. To start the program type:

```
java RobotsoccerSimulator
```

You should then see the program start up:

```
Starting SimAdministrator:
        - Creating settings...
        - ObjectFactory...
        - SimUpdater...
        - Match...
Starting CommAdministrator...
        - Collision handler...
Starting CtrlAdministrator
Starting GuiAdministrator...
        - creating scene...
        - creating 3D Field...
        - creating Gui3DField floor...
        - creating Gui3DField walls...
        - creating Gui3DField Goal3Ds...
        - creating Gui3DField field lines...
        - creating 3D Objects...
Displaying GUI...
```

Running a simulation

When the simulator has been started you can begin simulating a robot soccer match. The figure below displays the Graphical User Interface (or GUI) you should see before you:

File The file dropdown menu contains the options to start and stop the simulator. You can also close the simulator down from here.

Matches This dropdown menu enables you to adminstrate the matches which are present on the disk.

Snapshots Analogue to the matches dropdown menu, the snapshot dropdown menu enables you to administer the snapshots files which are present on the disk.

Options The options dropdown menu contains, logically, the options for team controllers. Also, collision detection, the FIRA game rules and warning messages can be toggled on or off here.

Help The help menu contains three items which each pops up a small window containing about, help and credits of the MiS20 respectively.

Soccer Field The soccer field represents the field on which the robot soccer match takes place. It is represented in three dimensions with a camera vantage point 4 meters above the central point of the field.

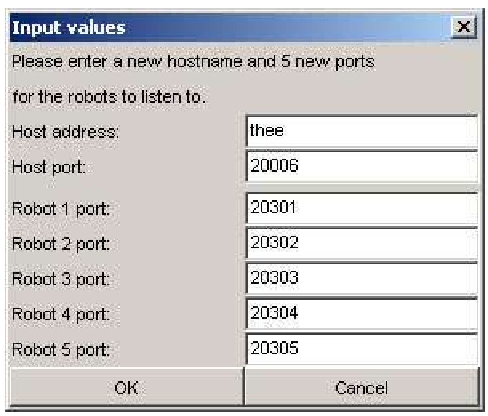
Buttons The buttons enable you to start and stop the simulation as well as to referee a match.

Messages The messages display system information from the simulator regarding loading and saving files from and to disk as well as general information on the simulation.

Object data Here, the data on the ball and the robots is displayed. The location of the object is displayed as well as its heading. Also, the speed of the object is displayed here. For a robot the speed of each of its two wheels is displayed.

Setting the team controllers

The robots of both teams are initialized to be controlled from the localhost machine. When running the control system for either of the two teams elsewhere, adjust these settings. Open the settings menu for the team whose controller is to be set (see program controls chapter). The figure below indicates what you should see.



Fill out the input fields as stated; host address and host port indicate where the snapshots from the simulator are to be sent. The other five input fields indicate the port numbers where the robot wheelspeeds are received from.

Start!

When all controller settings have been made, the simulator can be started. Use of the buttons in the right side of the window is recommended. Start the simulator by pressing the “start/resume sim” button. The simulation will now begin. The time will start to run in the upper left corner of the window and a message will be displayed in the message panel to indicate the simulator has been started.

Refereeing

A simulation will only approximate a real robot soccer match well enough when the FIRA game rules are applied to it. To that purpose the buttons starting with "Ref: " have been made. Use those to apply the various game rules as stated on the FIRA website: http://www.fira.net.

When a referee button has been pressed the appropriate action is undertaken by the MiS20. Some situations require you to select the team which will benefit from this rule (a popup will be displayed).

- **Free kick** The free kick situation is loaded for the chosen team;
- **Free ball** One of the four free ball situations will be loaded;
- **Penalty** The chosen team gets to take a penalty;
- **Goal kick** The chosen team gets to take a goal kick;
- **Start pos** The start positions are loaded for the two teams;
- **Goal scored** A goal has been scored, the score is updated and the start positions are loaded.

Match completed

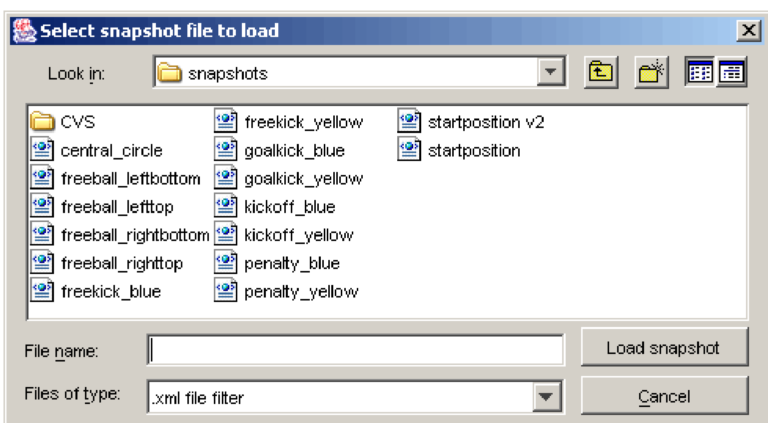
When a match is completed, its set gametime (10 minutes) is played, and if there is a winner the match will be saved to disk automatically (if this option is toggled on in the options menu). When there is a draw however, a sudden death scheme is applied for 3 minutes. If a team scores a goal within this time the match is completed as well. If there is still a draw after sudden death, penalty kicks will be taken, three for each team.

Managing the simulator

It is possible to adjust the snapshots which are loaded by the referee as well as the matches which have been logged to disk.

Snapshots

The bin/snapshots directory in the simulator directory contains all snapshots known to the simulator. These files are in XML layout. Using the dropdown menu "snapshots" you can administer these files; deleting, renaming, editting and saving are included. Each time a popup will be launched in which the snapshot directory and its contents is displayed.



Matches

Matches are administrered in the same way as the snapshots are. A match can also be reset using the "matches" dropdown menu. However, all data of the current match will be lost! So be carefull.

Replaying a logged match

The matches are logged to disk in XML files. These XML files can be read from that disk at a later time to review the match. The match is then displayed like a movie. This replayed match can be started and stopped just as a simulated match can be. However, the referee options are turned off since the match has already been refereed.

Credits

Producers:	Hans Dollen, Wim Fikkert
Interface:	Wim Fikkert
Communication:	Hans Dollen
Model design:	Wim Fikkert
Programming:	Hans Dollen, Wim Fikkert
Catering:	Hans Dollen, Wim Fikkert
Sounds:	Nobody
Special effects:	Nobody
Technical directors:	Hans Dollen, Wim Fikkert
Special thanks to:	Jan Meuleman, Mannes Poel, Hendri Hondorp
Reviewers:	Hans Dollen, Wim Fikkert, Lynn Packwood, Michiel Korthuis, Andre van der Zijden, Marieke Fikkert

Contact data

If you still have questions concerning this product, contact our Customer Support Centre at:

Telephone: none (workdays from 09:00 through 17:00)
E-mail: hdollen@hotmail.com
wimfikkert@hotmail.com
Post address: Saxion Hogeschool Enschede
Postbus 70000
7500 KB Enschede
Department: Hogere Informatica, Ir. J. Meuleman

Copyrights

Appendix C. Developers manual

This appendix is the developers manual for the MiS20. Future developers can use this document as a guideline for their adaptations. The MiS20 program has been constructed for reuse and expansion by other teams of software developers. This chapter will explain the areas which will, most likely, fall into this category. Software developers can use this information to easily implement those expantions. We will discuss how to create an automated referee and how to realize the various camera vantage point in the 3D soccer field representation.

C.1. Automated referee

Currently, the MiS20 program has been implemented with a manual referee. This referee (implemented in the *CtrlReferee* class) implements the *Referee* interface we created for each referee implementation to comply to. As described in the implementation document, the currently implemented referee requires a user to operate it.

An automated referee can be implemented by creating a new class, *CtrlAutoReferee* for example, which extends the *java.lang.Thread* class. This new *Thread* is best started in the *CtrlAdmin* class on creating of this class. The *SimAdministrator* can be asked if it is running using the *isBusy()* method. And if so, the *CtrlAutoReferee* class can determine if a referee call is required. Another approach is to add this functionality to the *SimUpdater Thread*'s *run()* method. This method will then decide, before or after calling the *updateObjects()* method of the *SimAdministrator* class if a referee call is needed.

The big difficulty of an automated referee is that will have to be able to not only detect when a goal has been scored or what to do when a goal kick is required. It will also need to be able to detect various game situations which require referee interferance. For example, a free ball situation is to be called whenever a stalemate occurs which lasts 10 seconds. But when does a match situation comply to such a stalemate?

This problem, accompanied by other similar problems, will have to be solved in order to create an effective automated referee.

C.2. Various camera vantage points

The MiS20 implementation document describes the method used to implement the camera in the MiS20. The *GuiCamera* class can be used to position the camera freely in the 3D world which represents the soccer field. A up *Vector3D*, and two *Point3D* classes have to set to move the camera to a new position. We use the lookat method of the *Transform3D* class to calculate the new camera position.

C.2.1. Pursuit camera

A camera which follows a specific object across the soccer field can be implemented by setting the selectObject with a specific object and having the *GuiCamera* class listen to vector property changes of that object. When a property change event has been caught by the GuiCamera the new camera position has to be calculated. The up *Vector3D* will not change, so only the lookAt and lookFrom *Point3D*'s have to be recalculated. The first can be set simply as the current *SimVector* values of the object being pursued. The latter has be calculated each time.

The easiest and best way to accomplish this task is to use a static difference Vector3D which always positiones the pursuit camera a bit behind and above the pursued object.

C.2.2. Free camera

A free cam can be implemented in two ways. The first is to use the *SimpleUniverse* with the Java3D default *OrbitBehavior* behavior. This behavior enables a user to move the camera freely about in the a 3D world. However, the controls are not user friendly in usage at all.

The second option is to use the lookat functionality we mentioned earlier in the *GuiCamera* class. The method used for moving the camera about has to be considered then; keyboard or mouse. If the mouse is used, the *MouseEvent*s can be used to alter the camera position. If the keyboard is used, the already created *CtrlActionListener* class can be expanded to add this functionality. A good way to use the keyboard is to use the arrow keys. Left and right indicate a spherical movement whilst up and down control zooming.

C.3. MiroSot small and large leagues

The MiS20 has been designed and implemented for usage in the FIRA MiroSot middle league in which two teams, consisting of five robots each, will play. However, the MiroSot league also contains a small and a large league competition in which three and seven robots per team respectively play each other. The rules are not very different in these leagues. It is therefore conceivable that the MiS20 would be altered to be used in these leagues as well.

We have taken steps to ensure this will be possible in the future. The steps a developer will need to take to accomplish this transformation are:

C.3.1. Field sizes

Set the correct field sizes in the *SimField* class. The small league has a smaller field in which the robots will play whereas the large league will have a larger soccer field to play in. The measurements of these soccer fields are stated in the FIRA regulations for the small and large leagues. These can be found on the FIRA website[1].

C.3.2. Snapshots

Create and store new snapshots for each of the situations a match can be in. These can be found, as with the situations in the middle league, in the FIRA regulations[1]. The snapshots are stored in XML files, as was described in the MiS20 implementation document. These files are stored with the prequel "5vs5_" indicating the number of robots in this snapshot. The snapshots for the small league are to be named "3vs3_" and the rest of their name. The large league snaphots will logically have "7vs7_" as a prequel.

C.4. Match settings

Currently, the settings for a match are stored in the SimSettings class mainly. The game duration time for example. It is very much conceivable to have these settings set by the user each time he or she starts a match. The settings which can be set here are:

- Team names (actual team names and not simply "MiSteam" and "Opponents");
- Game duration time. If tests have to be performed which require a shorter game duration, this can be a setting which the user may provide;
- Team colorings. In a real match both teams will be given a color by the referee. However, in the MiS20 it will not matter a great deal what color a team has since the teams are identified by number. The team color is just a indication in the GUI for the user. It might be usefull to change these colorings, but it will not have a great impact to do so.

[1]. Download these regulations on the FIRA website, reference [W7].

C.5. Improved collisions

As we have stated before, we designed and implemented the MiS20 program to be improved upon by others in the future. Here, we will describe how a new collision detection algorithm can be integrated into the MiS20. Also, we will describe how collision handling can be updated.

C.5.1. Detecting

A list of colliding objects is generated by looping through all objects in the match. This is done by the collision handler since it can reuse the object references which results in better performance. This list is then handled by the collision handler further. Collisions between objects in the MiS20 are detected using two levels of detection. First we use AABB collision detection to detect if a collision might be possible. If so, the second level of detection uses a combination of OBB and bounding sphere detection to detect collisions very precisely. These tests are performed in the *SimAdministrator* class' *calculateCollisions()* method.

This method will call upon an instance of the *SimCollisionHandler* class, currently called *SimHansCollisionHandler3*. This collision handler will first test for possible collisions using a static method of the *SimAABBCollisionDetector* class. This class can be altered or expanded upon so that the collision detection can improve.

The second phase of collision detection uses OBB and bounding sphere collision detection. The method calls for these collision detection techniques can also be found in the *SimHansCollisionHandler3* class. A new (possibly better) detection algorithm can be integrated here as well.

C.5.2. Handling

As described in the previous paragraph, the collision handling class calls the collision detection. This is done to improve performance by reusing object references. This paragraph will describe how a new and better collision handler can be implemented in the MiS20.

Looping through the list of colliding objects we generated using the collision detections we will handle the collisions using a kinematic model of the objects involved. The goal of handling collisions is to simulate an actual collision as best as possible. To accomplish that we need to use various physics aspects such as object weight, momentum, velocity, turning speed and so on.

The list of colliding objects consists of colliding lines for each of these objects. These lines are either front, back, left side or right side of a robot or a point for a ball. The *calculateCollisions(SimObject[])* method in the *SimHansCollisionHandler3* class contains our version of collision handling. This method is to be updated or replaced by future developers.

C.6. Kinematic models

We also use kinematic models to represent the robots and the ball apart from the collisions they can be involved in. These models included deceleration speeds etc. For example; when the ball is kicked by a robot, it will roll across the soccer field and will eventually come to a stop. The *SimBall* and *SimRobot* classes include a method called *updatePosition()* which will, as its name states, update the positions of the ball and robot. This is done differently for the ball and robot as is described in chapter three.

To improve upon these models, a developer will have to update these methods. A physics equation, such as the one we use which described in our design document[2], can be used to update the object vectors to their new values. Currently, we do not use skidding, drifting and noise movement for the ball and robots. These are points to be researched and implemented by future developers.

[2]. For the MiS20 design document, see reference [B1].

C.6.1. Skidding
Skidding occurs whenever an object tries to accelerate faster that it possibly can resulting in loss of movement force. This force cannot be transferred to the floor fully.

C.6.2. Drifting
Drifting occurs whenever an object, especially a robot, tries to turn to fast for its current velocity. It will not drift out of the turn.

C.6.3. Noise movement
The ball is as not perfectly round as we simulate it currently in the MiS20. It is an orange golf ball which means it has a number of small dents across its surface. This also implies that this ball will not move in a straight line always, it will move from side to side sometimes. This is very hard to simulate. The best way to accomplish a simulation of this behavior is to implement a noisy movement instead of a linear movement as we have done.

Appendix D. UML diagrams

This appendix contains the UML diagrams created in the design process.

D.1. Model

The model component of the MVC design principle mainly consists of a match. A match contains two teams and a ball. Each of those teams contain a set of five robots. Figure D.1 displays this the way it has been programmed in the MiS20.

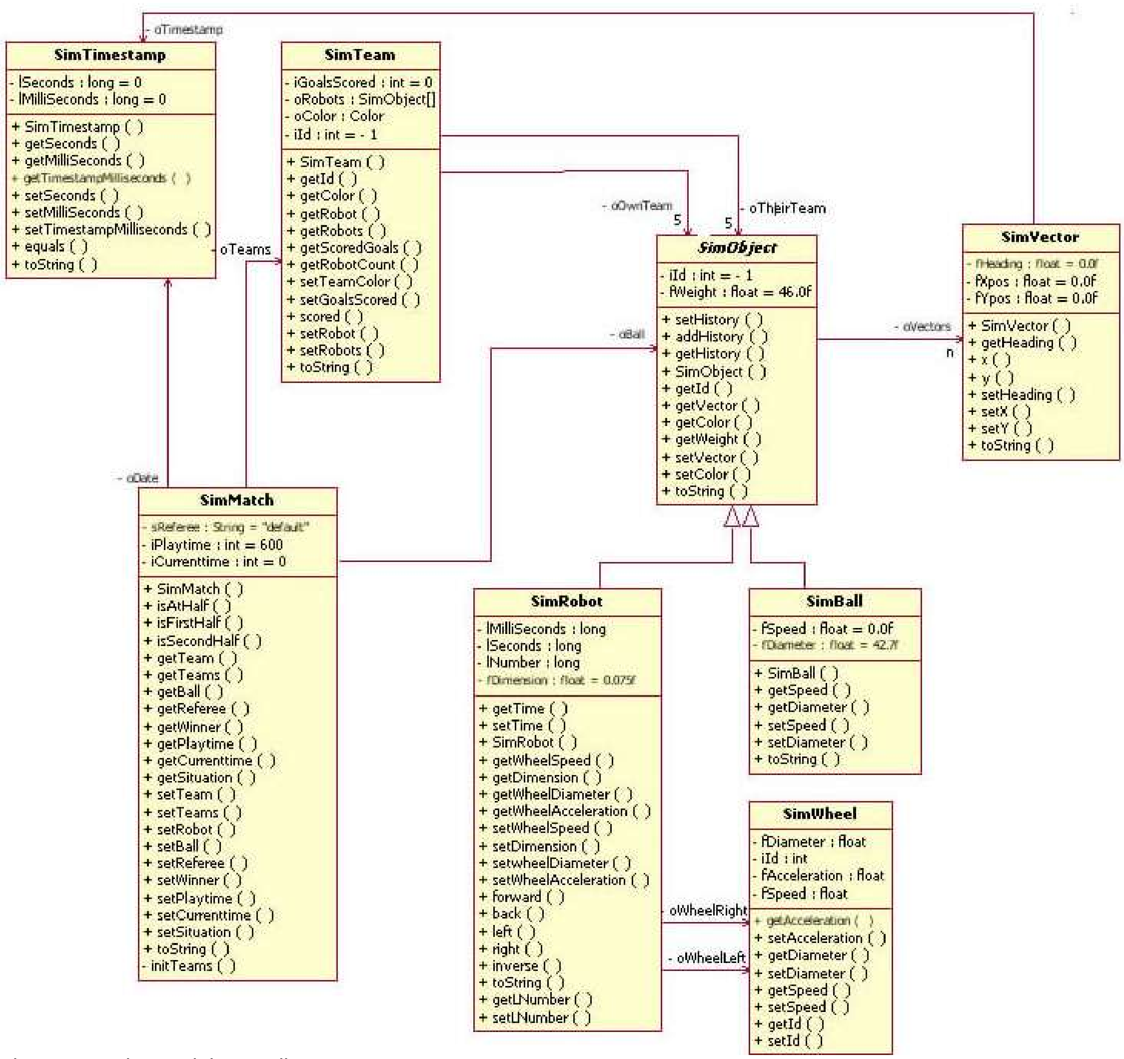


Figure D.1. The model UML diagram